Journal

WATER POLLUTION CONTROL FEDERATION

FORMERLY SEWAGE AND INDUSTRIAL WASTES

Special Features

Halogens in Sewage—McKee et al.

Treatability of Industrial Wastes—Symons et al.

Toxicity of Chromium—Trama and Benoit

Authority Financing—Zack

Ocean Dispersal of Chemical Wastes—Gill et al.

Operator's Corner

Small Treatment Plants, Public Liability

AUGUST 1960

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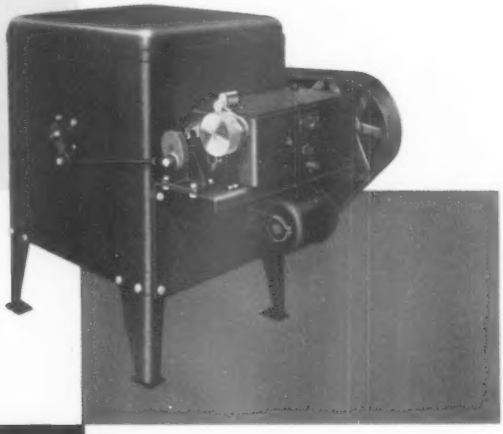

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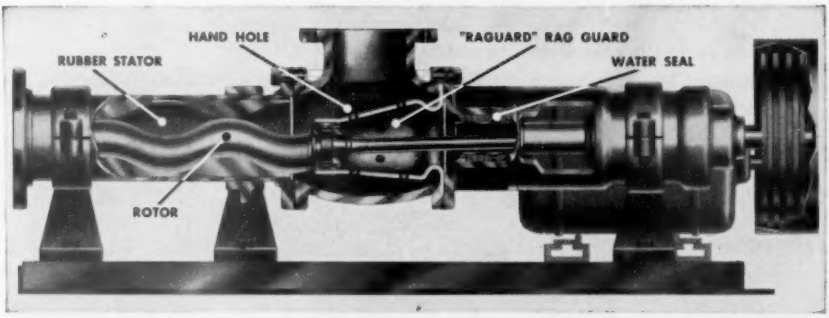

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Volume 32 | August 1960 | Number 8

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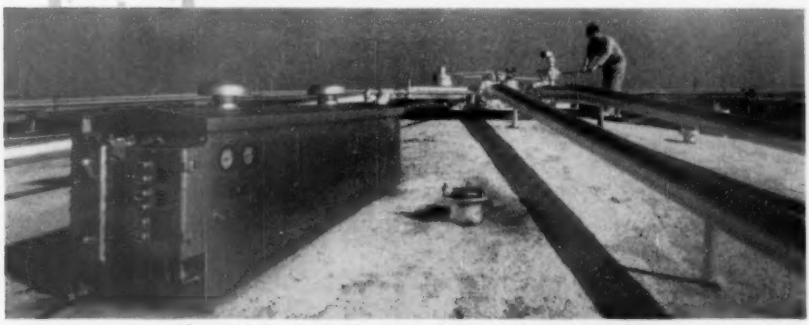
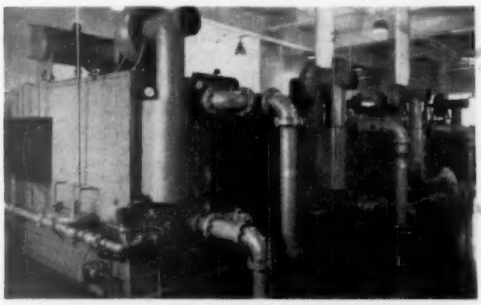


Above—P.F.T.'s Pearth Gas Recirculation equipment on newly added 95′ P.F.T. Floating Cover Digester.



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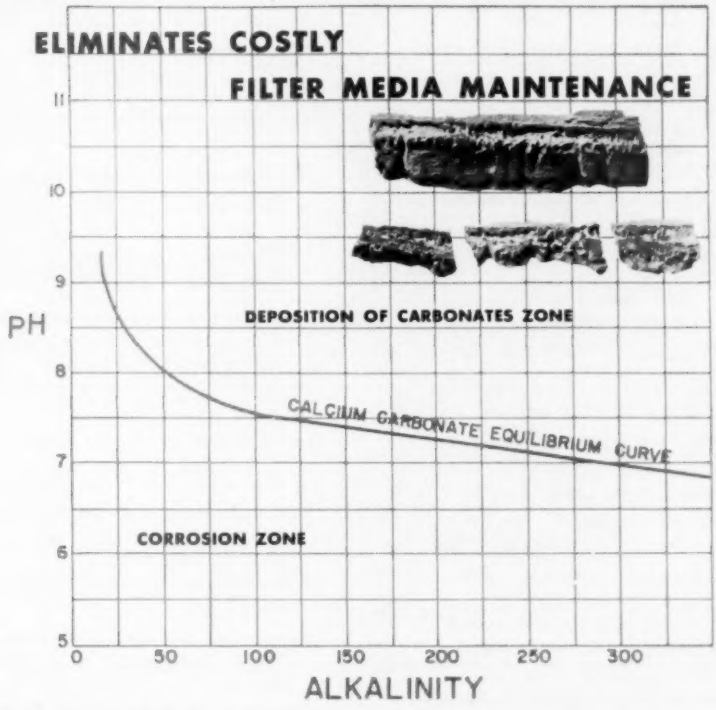

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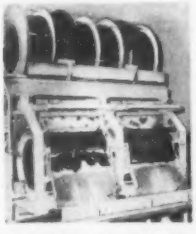

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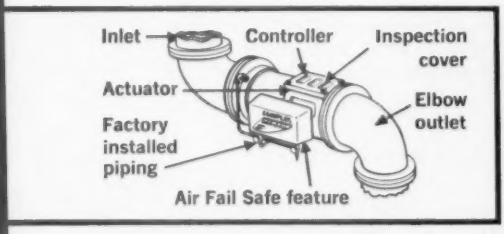

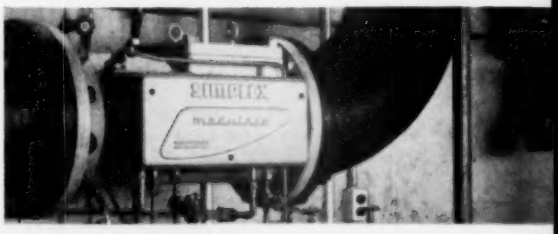

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South Dakota	Sept. 7–9	Grand Hotel, Watertown
Kentucky-Tennessee	Sept. 12–14	Andrew Jackson Hotel, Knoxville, Tenn.
Missouri	Sept. 25–27	Hotel Governor, Jefferson City
North Dakota	Oct. 5–7	Grand Pacific Hotel, Bismarck
Pacific Northwest	Oct. 20–22	Marcus Whitman Hotel, Walla Walla, Wash.
Canada	Oct. 23–26	Sheraton-Brock, Niagara Falls, Ontario
Rocky Mountain	Oct. 24–26	Broadmoor Hotel, Colorado Springs, Colo.
New England	Oct. 26–27	Taft Hotel, New Haven, Conn.
Nebraska	Nov. 3–4	Castle Hotel, Omaha
South Carolina	Nov. 4	Jefferson Hotel, Columbia
North Carolina	Nov. 9–11	R. E. Lee Hotel, Winston-Salem
Florida	Nov. 13–16	Galt Ocean Mile Hotel, Fort Lauderdale
Oklahoma	Nov. 14–18	State University, Stillwater
Indiana	Nov. 16–17	Hotel Washington, Indianapolis

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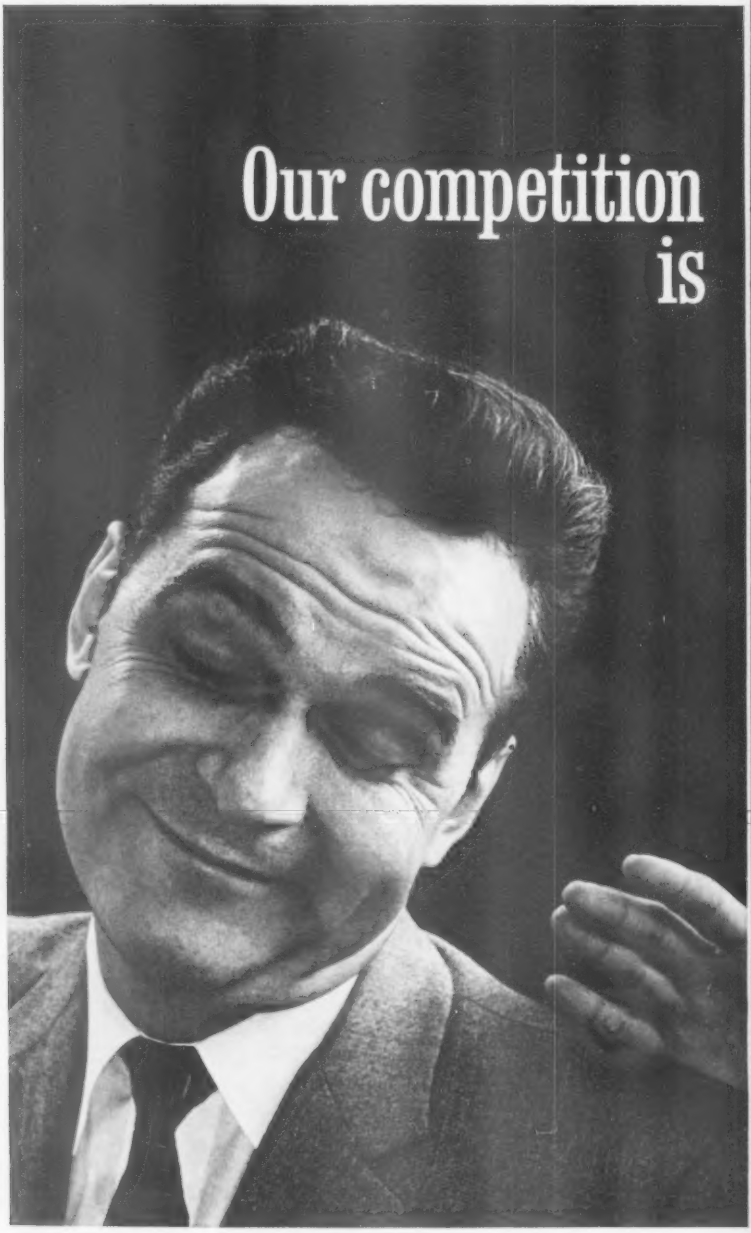
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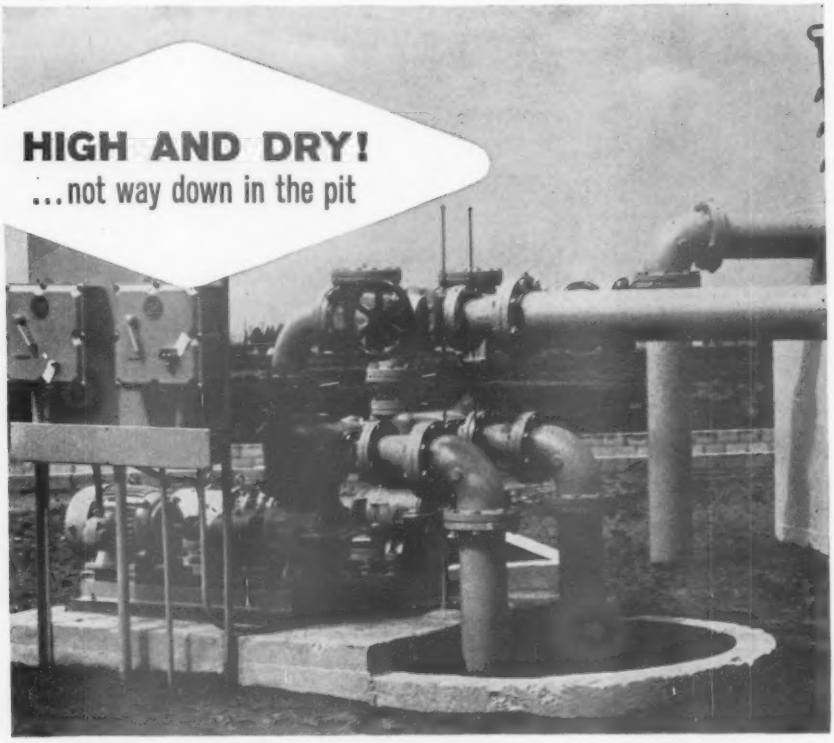

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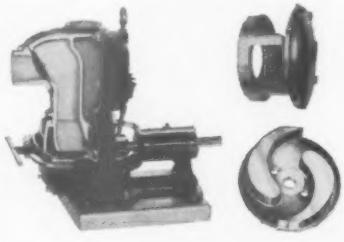

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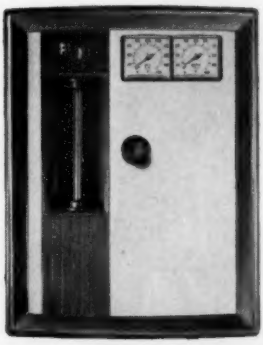

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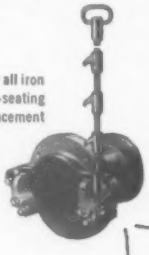

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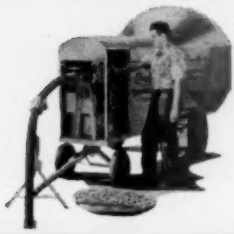

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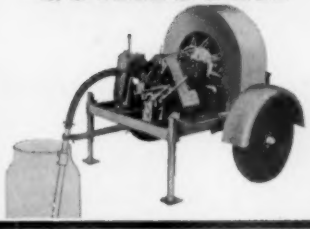

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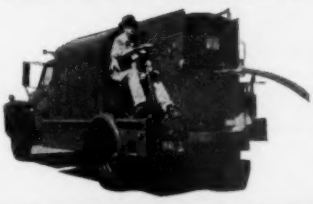

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Eimco-Process Type ADC Aerobic Digestion plant for sewage treatment, Air Route Traffic Control Center. Consulting Engineer, Walter J. Parks, Jr.

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Eimco-Process Type GSW Grit Washer Mechanism in municipal sewage treatment plant. City of Colorado Springs, Department of Public Utilities.

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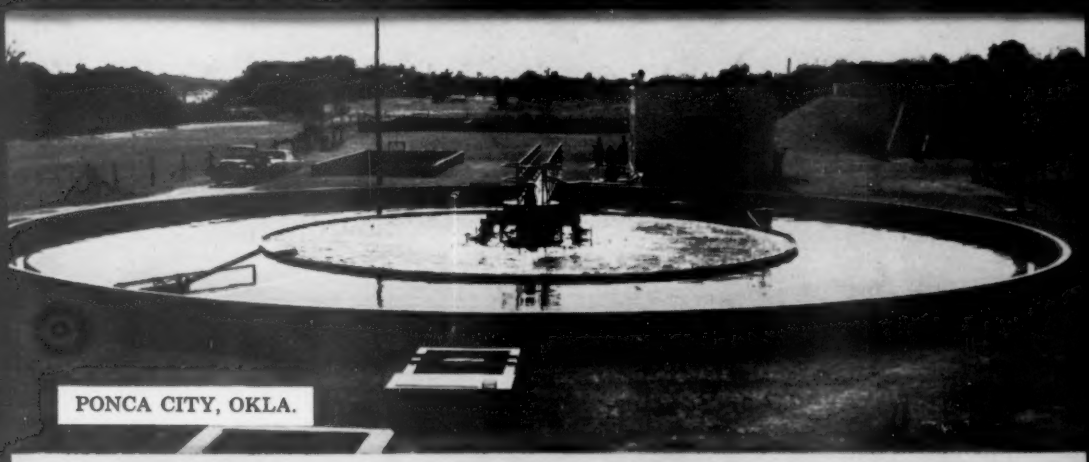
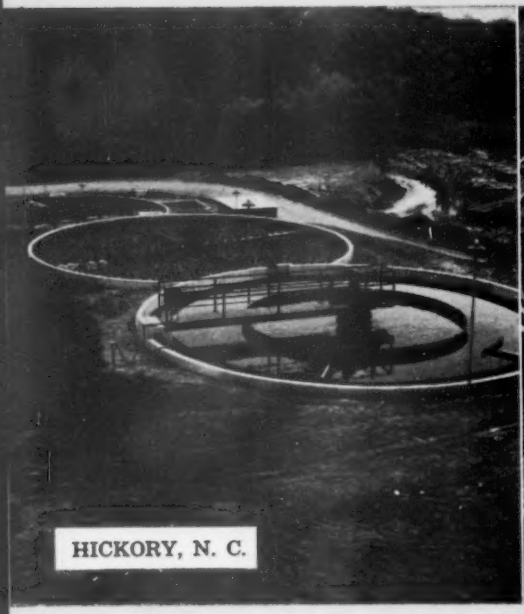


90-foot diameter Eimco-Process Type CSP Primary Oxidator. Pate Engineering Co., Consulting Engineers.



40-foot diameter Eimco-Process Reactor-Clarifier and two Rotary Distributors for 50-foot diameter filters. Abernethy and Scott, Consulting Engineers.

Type CSP, 45-foot diameter Eimco-Process Sludge Thickener for municipal sewage treatment plant addition, John A. Carollo, Consulting Engineer.

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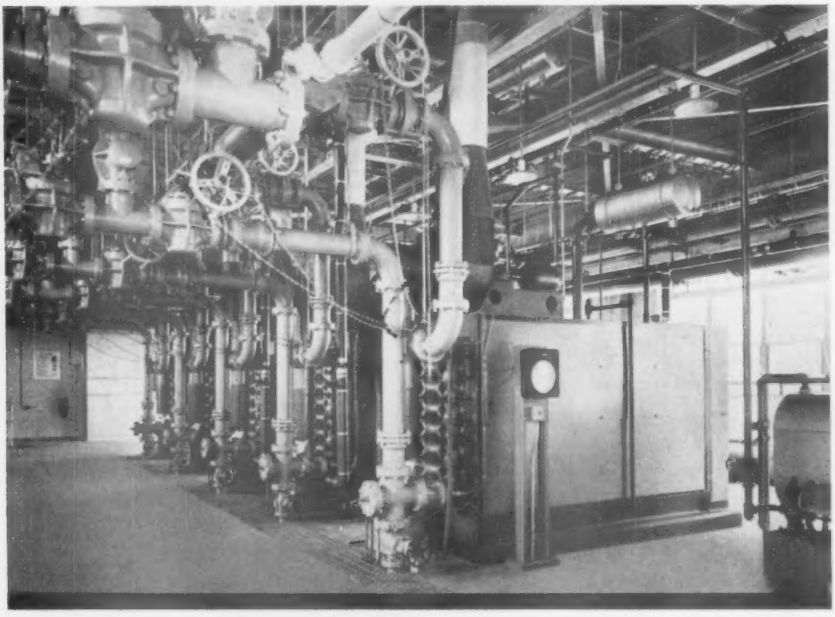
View of Sludge Heating and Digestion Building. Metal was shop-primed with Inertol Rustinhibitive Primer 621. Masonry wall and ceiling areas were primed with Ramuc® Utility Undercoater. Ramuc Utility Enamel was then applied to all primed surfaces. Special Inertol high-heat paints were used where required. Here—and in many other areas throughout the entire plant—Inertol specialized coatings will protect efficiently, attractively, economically...for *many* years.



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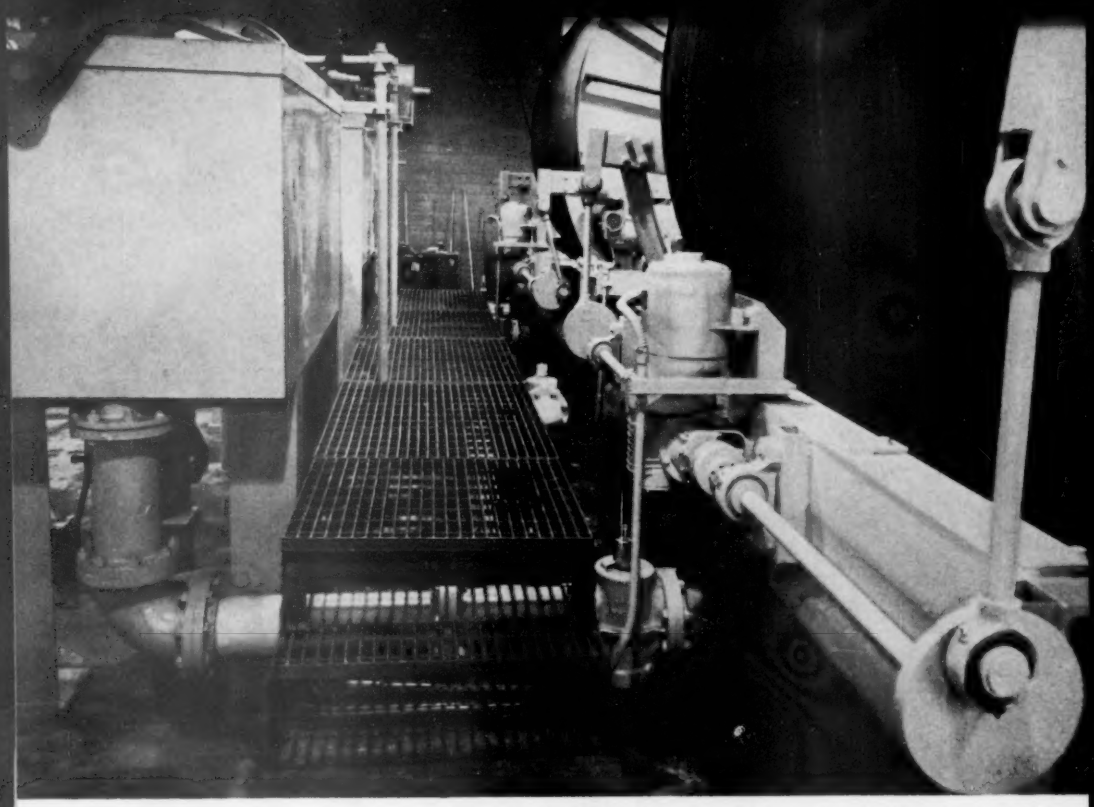
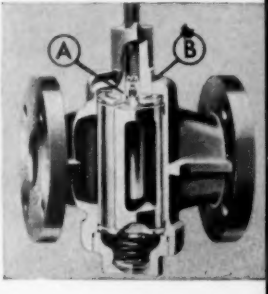


Homestead Lubricated Plug valves at work in Bloom Township Sewage Treatment Plant. Consulting Engineer for installation: Consoer, Townsend and Associates, Chicago.

"Five years—and not a cent for replacement parts!" . . the facts from Sanitary District of Bloom Township

Installed in 1955, Homestead® Lubricated Plug Valves have carried 60,000 gallons of digested sludge from the conditioning tanks to the vacuum filters *every week*. The only maintenance required has been repainting one time.

Homestead's Lubricated Plug Valves mean lower maintenance costs . . . as proved at the Sanitary District of Bloom Township Sewage Treatment Plant in Chicago Heights, Illinois. Homestead Valves can mean lower maintenance costs of *your* pipe lines, too. Write today for complete information.



Cross-section of Homestead Lubricated Plug Valve. Triple head seal (A) prevents leakage. Tell-tale lubricant ring at (B) signals full system, prevents waste of lubricant and contamination of line fluids.

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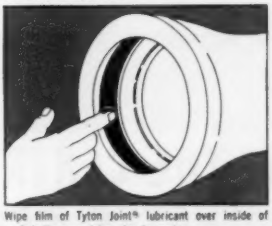
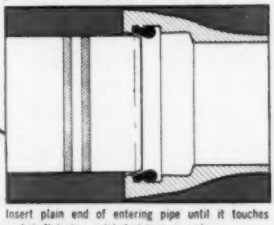
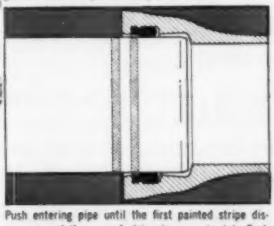


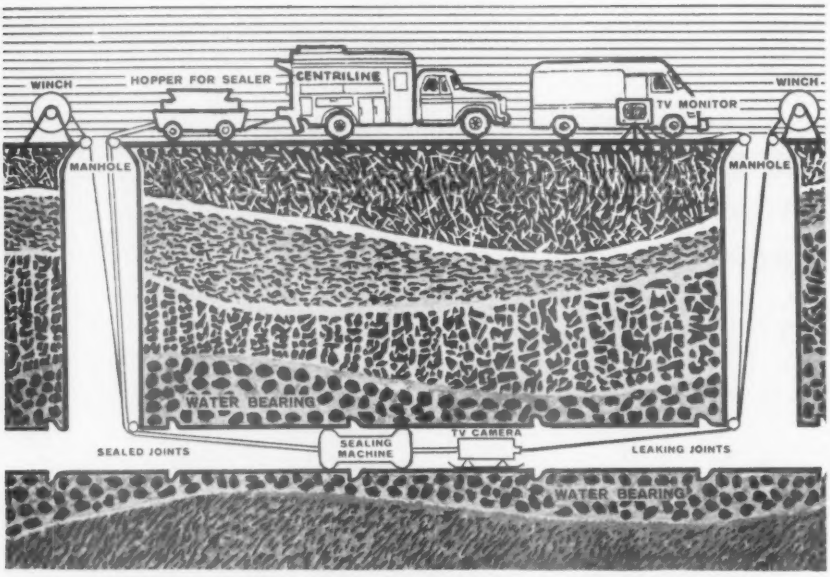
Wipe film of Tyton Joint® lubricant over inside of gasket. Your receiving pipe is ready.



Insert plain end of entering pipe until it touches gasket. Note two painted stripes on end.



Push entering pipe until the first painted stripe disappears and the second stripe is approximately flush with bell face. The joint is sealed . . . bottle-tight, permanently! The job's done . . . . fast, efficiently, economically. Could anything be simpler?



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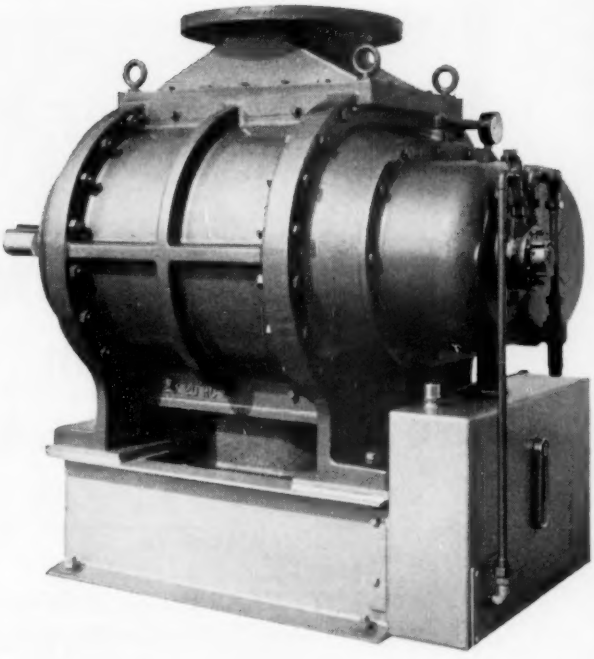

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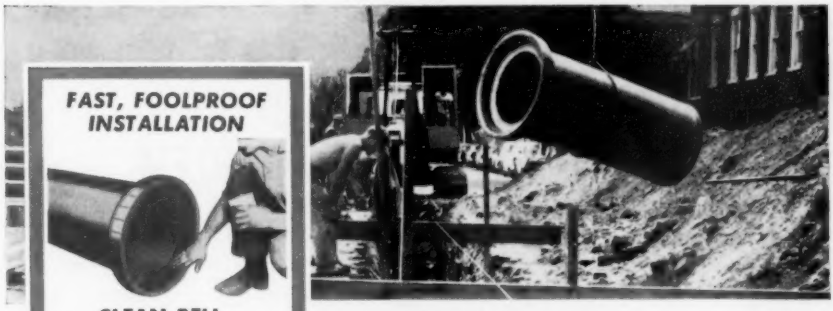

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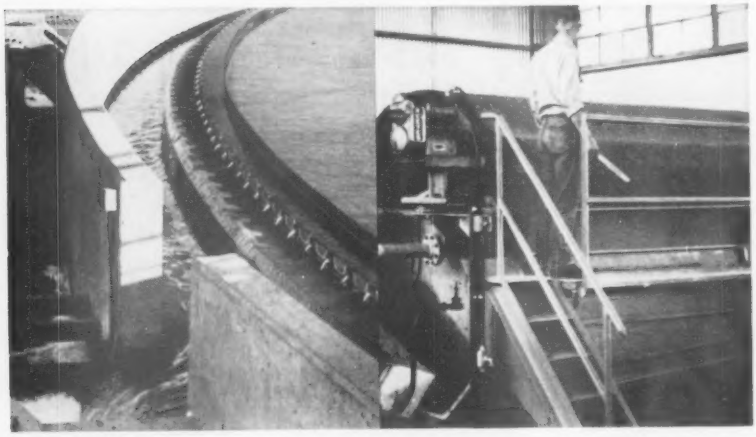

Clean water from Dorr Clarifier flows down aeration ladder on way to settling basin.

Sludge from Clarifier is pumped to Oliver Vacuum Filter for dewatering prior to disposal.

Diamond Gardner's new integrated forest products plant at Red Bluff, Calif., is a model installation for complete utilization of the timber harvest.

Before this model project could get off the drawing board, the company had to provide a plan for disposing of plant effluent that would win state approval.

The efficient waste treatment plant, designed by the company engineers, uses Dorr-Oliver equipment. Effluent from pulp and molding processes flows to a Dorr Clarifier, where flocculents are metered in. The resulting water flows down aerating stairs en route to a three-compartment, 9¼-acre settling basin.

Sludge recovered from the Dorr Clarifier is fed to an Oliver rotary drum Vacuum Filter designed to operate either as a precoat unit or with roll discharge.

Dorr-Oliver has a wealth of experience and diversified equipment to solve waste disposal problems. Write to Dorr-Oliver Incorporated, Stamford, Connecticut.

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Sewage Works

CHEMICAL AND COLICIDAL EFFECTS OF HALOGENS IN SEWAGE *

By Jack E. McKee,† Charles J. Brokaw,‡ and Ronald T. McLaughlin §

Division of Engineering, California Institute of Technology, Pasadena, California

CHEMICAL CONSIDERATIONS

Chlorination is recognized as the cheapest method for disinfection of water and liquid wastes. Other halogens cannot be expected to compete economically with chlorine, especially in sewage treatment. Yet, an investigation of their chemical effects and colicidal action was undertaken with the hope that it would lead to a better understanding of the mechanisms by which halogens kill or inactivate pathogenic organisms.

The experiments described in this report were designed to explore the actions of halogens as part of a project dealing with many methods for the disinfection of settled sewage. The first part of the study relates to the chemical considerations while the second part covers the colicidal effects.

Pasadena sewage was used for all experiments. Samples were taken from the trunk sewer of the Los Angeles County Sanitation Districts near the site of the abandoned Tri-Cities Sewage Treatment Plant. Serving Pasadena and contiguous communities with a sewered population of about 200,000, this sewer contains representative domestic sewage, with very little industrial wastes and no groundwater infiltration. Velocities are high and the sewage is quite fresh at the point of collection. To assure an approximate degree of uniformity, samples were always taken between 8 and 9 AM on a week day, with no rain.

Halogens as Disinfectants

Fluorine (atomic weight 19.0), the lightest and most electro-negative halogen, is too reactive for use in sewage treatment. Because it attacks almost every material, it is difficult to store and apply. Indeed, its extreme reactivity has discouraged the study of fluorine as a disinfecting agent although its germicidal power may be expected to be great. It has not been considered further in this investigation.

Chlorine (atomic weight 35.5), the second lightest halogen, is the most common in nature and the least expensive. A poisonous, yellow-green gas at ordinary temperatures and pressures, it can be handled and stored safely when free from water and it is amenable to proper measuring and dosing equipment.

Bromine (atomic weight 79.9), a red

* Presented at the 32nd Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Dallas, Tex.; Oct. 12–15, 1959.

† Professor of Sanitary Engineering.

‡ Present address: Department of Zoology, University of Minnesota, Minneapolis, Minn.

§ Present address: Sanitary Engineer, World Health Organization, Bangkok, Thailand.

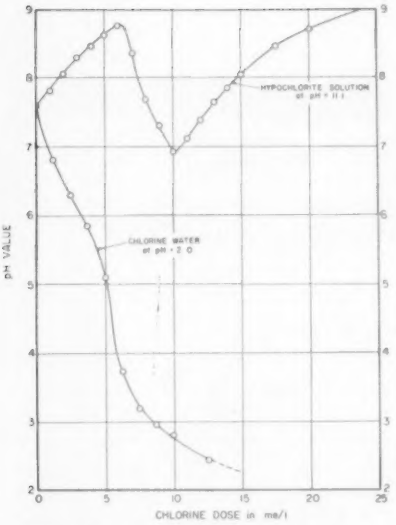

FIGURE 1.—Effect of hypochlorite solution and chlorine water on the pH of settled Pasadena sewage.

liquid at ordinary conditions, has been used occasionally for disinfection of swimming pools, especially when chlorine was in short supply. Physiological reactions have prevented its application to drinking water.

Iodine (atomic weight 126.9), the heaviest halogen, is a violet-black solid at ordinary temperatures. It has been used extensively as a germicide in medical practice and more recently, as a disinfectant for small quantities of drinking water.

Chlorine Hydrolysis and Dissociation

When gaseous chlorine, Cl_2, is added to water, the following equilibrium is established:

$$Cl_2 + H_2O \rightleftharpoons HOCl + Cl^- + H^+ \ldots (1)$$

Half of the chlorine is reduced to chloride ion (Cl^-) while the other half is oxidized to Cl^+ in the hypochlorous acid molecule. Thus, the oxidizing power is transferred to the HOCl molecule. The equilibrium constant for this reaction, given by Jakowkin and reported by Moore (1), is about 3×10^4 at 15°C; hence, at pH values of 3 or higher and chlorine dosages less than 1,000 mg/l, the reaction goes to the right almost completely. Moore also indicates that equilibrium is reached within a few seconds at ordinary temperatures. Consequently, all of the chlorine may be considered to be hydrolyzed to HOCl almost instantaneously. If pure water is saturated with chlorine, the pH falls to 2, owing to the release of H^+ ions.

Being a weak acid, the HOCl molecule dissociates as follows:

$$HOCl \rightleftharpoons H^+ + OCl^- \ldots\ldots (2)$$

where $\frac{[H^+][OCl]}{[HOCl]} = 3.3 \times 10^{-8}$ at 20°C,

according to Moore (1). For this relationship, it can be shown that about 97 per cent of the chlorine is in the form of HOCl at pH 6, about 75 per cent at pH 7, only 23 per cent at pH 8, and less than 3 per cent at pH 9. If, instead of gaseous chlorine, sodium hypochlorite is added to water, it dissociates to produce hypochlorite ion, thus

$$NaOCl \rightarrow Na^+ + OCl^- \ldots\ldots (3)$$

but some of the hypochlorite ions pick up hydrogen ions to establish the aforementioned equilibrium (Equation 2). The removal of free hydrogen ions causes the pH to rise.

A comparison of the pH changes that result from the addition to settled Pasadena sewage of chlorinated water (pH = 2) and sodium hypochlorite solution (pH = 11.1) is presented in Figure 1. The chlorine dosages shown here are exaggerated when compared with those normally used for sewage disinfection, i.e., less than one me/l (1 me/l = 35.5 mg/l of chlorine). As shown by Figure 1, one me/l of chlorine from hypochlorite raised the pH from 7.6 to 7.8, while the same dosage from chlorine water lowered the pH from 7.6 to about 6.9. The wave in the hypochlorite curve is due

to the breakpoint effect, which will be discussed below.

The pH effect is important in water chlorination because it determines the molecular status of the chlorine. As described by Moore (1), the HOCl ion is 45 to 250 times as effective as OCl^- in killing *E. coli* and *E. histolytica,* and the ratio of HOCl to OCl^- increases as the pH is lowered. In sewage, however, HOCl and OCl^- exist only momentarily; hence the pH effect is important as it relates to the products of chlorine and ammonia.

The experiments described in this report involved sodium hypochlorite solution rather than chlorine water. Most of the dosages, however, were in the range of 10 to 30 mg/l of chlorine, or less than one me/l, so the pH changes were not great. Sawyer (2) has demonstrated the efficacy and possible advantages of hypochlorite disinfection of sewage.

Formation and Breakdown of Chloramines

Most domestic sewages contain ammonia in concentrations of 1.0 to 3.0 millimols per liter, either in the form of ammonium ion, NH_4^+, or ammonium hydroxide, NH_4OH, as controlled by the equilibrium:

$$NH_4OH \rightleftharpoons NH_4^+ + OH^- \quad \ldots (4)$$

The dissociation constant for this reaction at 25°C is 1.8×10^{-5}; consequently, NH_4^+ will predominate at pH values lower than 9.

Hypochlorous acid may react with ammonium ion to form three chloramines:

$$NH_4^+ + HOCl \rightleftharpoons H_2O + H^+ + NH_2Cl \text{ (monochloramine)} \quad \ldots (5)$$

$$NH_2Cl + HOCl \rightleftharpoons H_2O + NHCl_2 \text{ (dichloramine)} \quad \ldots (6)$$

$$NHCl_2 + HOCl \rightleftharpoons H_2O + NCl_3 \text{ (trichloramine or nitrogen trichloride)} \quad \ldots (7)$$

These three equilibria might indicate that the first amounts of HOCl added to a solution containing ammonia would produce monochloramine until all ammonia has reacted, that subsequent increments of HOCl would convert the monochloramine to dichloramine, and that heavy additions of HOCl would form NCl_3. Such is not the case, however, for the ratios of chloramines are controlled largely by the pH of the solution. Recent work (1) has shown that mono- and dichloramine are in equilibrium with ammonium ion as follows:

$$2NH_2Cl + H^+ \rightleftharpoons NH_4^+ + NHCl_2 \quad \ldots (8)$$

The equilibrium constant for this reaction is reported to be 6.7×10^5 at 25°C, thus

$$\frac{[NH_4^+][NHCl_2]}{[H^+][NH_2Cl]^2} = K = 6.7 \times 10^5. \quad (9)$$

Consequently, the proportions of monochloramine and dichloramine are dependent on the initial concentrations of ammonia, the dosage of chlorine or hypochlorite, the resulting pH of the solution, and the temperature. Nitrogen trichloride does not appear to exist in significant quantities above pH 5.

If the original concentration of ammonia in aqueous solution, expressed as millimols per liter, is designated as $[A]$; and the hypochlorite dosage, also in millimols per liter, as $[D]$; then their ratio, Z, in ammoniated water will be

$$Z = \frac{[D]}{[A]} = \frac{2[NHCl_2] + [NH_2Cl]}{[A]} \quad \ldots (10)$$

It may also be noted that, by definition,

$$[A] = [NH_4^+] + [NH_2Cl] + [NHCl_2] \quad \ldots (11)$$

In sewage, Z will be somewhat lower because a fraction of the hypochlorite dose will be consumed by other reactions. When hypochlorite is added to

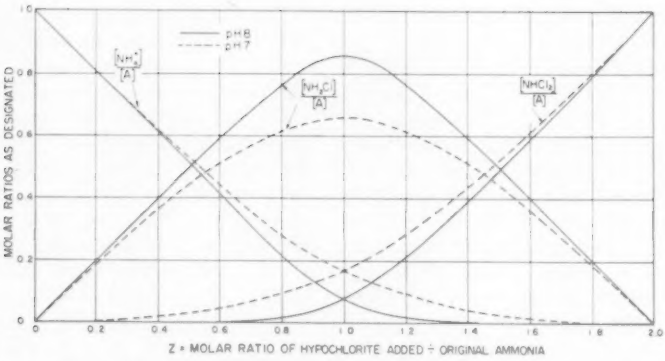

FIGURE 2.—Molar ratios of chloramines in ammonia solutions at 25°C.

pure water containing a few millimols of ammonia, it can be demonstrated from the equilibrium reaction between mono- and dichloramine that

$$\frac{[NH_2Cl]}{[A]} = \frac{1 - \sqrt{1 - Z(2 - Z)B}}{B} \quad . (12)$$

where $B = 1 - 4K[H^+]$ and $K = 6.7 \times 10^5$. Also

$$\frac{[NHCl_2]}{[A]} = \frac{1}{2}\left(Z - \frac{[NH_2Cl]}{[A]}\right) \quad . . (13)$$

and

$$\frac{[NH_4^+]}{[A]} = 1 - \frac{[NHCl_2]}{[A]} - \frac{[NH_2Cl]}{[A]} \quad . . (14)$$

An evaluation of these three equations at pH 8 and pH 7 leads to the curves shown in Figure 2. At lower pH values, the curve for monochloramine is much flatter and the dichloramine curve correspondingly higher.

If a sewage contains one millimol per liter of ammonia (or 17 mg/l, a value exceeded in most sewages) the Z value will be 0.5 for a hypochlorite dosage of 0.5 millimols per liter, or 35.5 mg/l of chlorine. This is a heavier dose of chlorine than is normally used in practice. Yet, Figure 2 shows that only about half of the ammonia would be converted to monochloramine for this Z value at pH 8, and that practically no dichloramine would exist. Only at very high chlorine dosages (i.e. at $Z > 1.0$ or more than 71 mg/l of chlorine), or at low pH values, would significant concentrations of dichloramine appear and the remaining traces of ammonia reach the vanishing point. At $Z = 2$, all of the ammonia would be converted to dichloramine in accordance with Figure 2; but this conversion is limited by oxidation or decomposition of the dichloramine and possibly of the monochloramine. This phenomenon is known as "breakpoint" chlorination.

The exact mechanism of the "breakpoint" reaction, and the intermediate and final products, have not been determined definitely. The chloramines may be oxidized to form nitrogen gas, hydrogen, and chloride ions in accordance with these formulas:

$$NH_2Cl + NHCl_2 \rightarrow N_2 + 3H^+ + 3Cl^- \quad . . (15)$$

or

$$NH_2Cl + HOCl \rightarrow N_2 + H_2O + 3H^+ + 3Cl^- \quad . . (16)$$

Certainly the phenomenon is characterized by a decrease in the chlorine residual (i.e., a decrease in total chloramines) and a lowering of the pH attributable to the release of hy-

drogen ions. It is shown graphically in Figure 1 where hypochlorite raised the pH until 6 me/l had been added. Then the pH dropped until the hypochlorite dosage reached 10 me/l, where oxidation of the ammonia was completed. Figure 3 shows a pair of breakpoint curves. Both the chlorine residual and the pH value reflect the breakpoint.

Morris *et al.* (3) maintain that reaction between $NHCl_2$ and NH_2Cl does not play a part in the breakpoint and they indicate that nitrogen oxide rather than nitrogen gas is formed. Their proposed mechanism for the decomposition of dichloramine involves NOH as an intermediate, thus:

$$NHCl_2 + H_2O \rightarrow NOH + 2H^+ + 2Cl^- \quad (17)$$

$$2NOH + HOCl \rightarrow 2NO + H_2O + H^+ + Cl^- \quad (18)$$

The NO formed in this reaction would combine with oxygen in the water to give NO_2, and be oxidized eventually to nitrate.

If chlorine dosages are continued beyond the trough of the breakpoint curve, the absence of ammonia nitrogen or of chloramines will allow the chlorine to remain "free" as HOCl or OCl^-, presumably at its greatest disinfecting power. Although this fact is utilized in chlorinating drinking water supplies beyond the breakpoint, the dosages required to reach the breakpoint of settled sewage are generally impractical. The 10 me/l in Figure 1 corresponds to a dosage of 355 mg/l or about 2,960 lb/mil gal. At 6¢/lb, the chlorine dosage to reach the trough of the breakpoint would cost $178/mil gal.

Moore (1) has indicated that "a water of 25°C receiving 0.8 mg/l of chlorine and 0.32 mg/l of ammonia nitrogen will convert 99 per cent of the chlorine to monochloramine in 1 minute at 8.3" (the optimum pH). At other pH values, the rate will be slower; but at the considerably higher ammonia concentrations found in sewage, the reaction will be rapid enough so that HOCl and OCl^- will be present only momentarily in concentrations greater than those resulting from equilibrium with chloramines.

This point is highly significant, for it means that the disinfection of settled sewage, through much of the contact period, will be attributable either to monochloramine, or to the small concentrations of HOCl released from monochloramine by the equilibrium reaction. If monochloramine, per se, is actually germicidal, as most investigators believe it to be, its effectiveness is much poorer than that of HOCl.

Besides reacting with the free ammonia of sewage, chlorine will combine with amino acids, proteinaceous material, and many other sewage constituents. Ingols *et al.* (4) indicate that reactions with amino acids such as alanine may produce organic chloramines, e.g.,

$$CH_3CHNH_2COOH + HOCl \rightleftharpoons CH_3CHNHClCOOH + H_2O \quad (19)$$

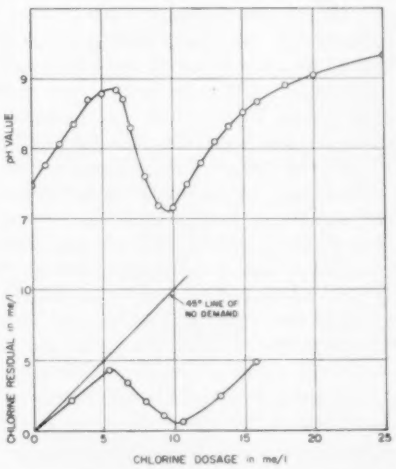

FIGURE 3.—Breakpoint phenomenon for Pasadena sewage as shown by chlorine residual and pH (15-min contact).

but little is known concerning the extent of such reactions, their reversibility, or the disinfecting power of the products. The organic chloramines may be as important as the inorganic chloramines. Indeed, some of the more complex chlorinated compounds may in themselves be specifically bactericidal or bacteriostatic. With the variety of possible substances in sewage and their variability from time to time, the knowledge and control of all possible reactions are difficult.

Being strong oxidizing agents, chlorine and hypochlorous acid will react with reduced substances such as sulfides, sulfites, nitrites, and ferrous or manganous ions. In these reactions, the chlorine is reduced to the stable chloride; hence it is no longer bactericidal. Sewages that have become anaerobic will abound in reduced substances and consequently such sewages will have a high chlorine demand.

To make a complete theoretical assessment of the bactericidal effect on sewage of a given chlorine dose, would require knowledge of: (*a*) the partial bactericidal effectiveness of each of the many products of the reactions among chlorine and sewage constituents, and (*b*) the concentration of each of these products at all times during the period of action. Some of the important compounds that may be present and may exert bactericidal or bacteriostatic action are: Cl_2, HOCl, OCl^-, NH_2Cl, $NHCl_2$, the organic chloramines, and other chloro-organic compounds about which little is known. It is evident, therefore, that the bactericidal action is determined not only by the chlorine dose, pH, and time of contact, but also by the nature and concentration of organic compounds and reducing substances in the sewage. A complete knowledge is lacking of the various chemical equilibria involved, and of the bactericidal potency of each compound that may occur in chlorinated sewage.

A survey of published work reveals that elemental chlorine is the most effective form of this substance, if it is ever present. Next in potency is HOCl, which is very much more effective than OCl^-, presumably because the neutral molecule will diffuse readily through the bacterial cell wall while the charged ion penetrates less easily. Monochloramine is variously reported to be from slightly to substantially less active than HOCl, depending on the organism tested and the temperature. Dichloramine is generally agreed to be somewhat more germicidal than monochloramine. It has been suggested, furthermore, that the entire bactericidal effectiveness of the various chloramine compounds is due entirely to the HOCl liberated by their hydrolysis. The precise work necessary to evaluate this hypothesis has not been accomplished to date, but there are indications that it is not completely the case.

The Determination of Chlorine Residual

In evaluating the effect of chlorine compounds for the disinfection of water or sewage, it is conventional to correlate the bacterial kill with the concentration of chlorine remaining after a specified contact time. The term "chlorine demand" is used to describe the difference between the amount of chlorine applied and the residual concentration remaining at the end of the contact period. In applying the criterion of residual chlorine, it is assumed that the effectiveness of bactericidal action is a function of the chlorine remaining; consequently, the existence of a high chlorine residual is considered to be prima facie evidence of effective disinfection.

Such is not always the case. In satisfying the chlorine demand, many of the chlorine or hypochlorite molecules may have already achieved their objective, viz., the killing or inactivation of pathogens or coliforms. Chlo-

rine dosages insufficient to produce a chlorine residual are nonetheless effective in reducing the concentration of indicator organisms. In deciding whether to correlate colicidal action with chlorine dosage or with chlorine residual, a review of the methods of measuring chlorine residual, and their significance, is in order.

"Standard Methods" (5) outlines three alternate procedures for the determination of residual chlorine in sewage: (*a*) the amperometric method, (*b*) the starch-iodide technique, and (*c*) the orthotolidine procedure. Experience during the course of this project indicated that the orthotolidine (OT) procedure was unreliable and erroneous, inasmuch as the residuals measured thereby were much lower than the corresponding starch-iodide values. The OT readings depended on the time interval between dosing with OT and reading the residual. With Pasadena sewage, the OT color developed partially on contact, rose to a maximum in 1 to 4 min, and then faded prior to the standard 5-min reading. Inasmuch as the OT should react with the hypochlorite and chloramines in the dark, it is nearly impossible to read the maximum color prior to fading. Moreover, there appear to be many substances in sewage that interfere with the OT reactions, so that this method of measurement is considered to be unreliable. Sawyer (2) notes also that OT residuals in sewage are lower than those measured amperometrically.

The acid starch-iodide procedure, as described in "Standard Methods" (5) was used in this research, but with a significant modification. In the conventional procedure, the chlorinated sewage (normally 200 ml) is added to a flask containing an excess of KI, a pH-4 buffer, and a known excess amount of standard thiosulfate solution. Some of the iodide is oxidized by the hypochlorite or monochloramine in the sewage to tri-iodide (I_3^-), which reacts immediately with the thiosulfate, presumably before any free iodine can combine with organic substances in the sewage. As will be shown later, iodine is more reactive with the organic substances in sewage than is monochloramine. However, the monochloramine will not react stoichiometrically with thiosulfate in the absence of KI or at this pH. Nusbaum (6) has suggested other analytical methods involving the direct addition of thiosulfate to chlorinated sewage.

After reacting with the released iodine, the remaining thiosulfate is titrated with a standard iodine (or another suitable standard oxidizing solution). In these titrations, the starch-iodide endpoint may be used; however, methods have been developed using amperometric means for determining the endpoint. As the standard iodine is titrated into the sample (to which starch has been added), each drop creates a blue spot until it is neutralized by the excess thiosulfate. At the endpoint, the blue color will persist throughout the sample. Despite the starch, however, the endpoint is not sharp. Its detection can be facilitated by constant comparison with a duplicate sample to which iodine is not being added. When the titrated sample becomes slightly more bluish than the non-titrated one, the endpoint has been reached. Obviously, this interpretation of the endpoint is subject to human variability, and for this reason it is believed that an endpoint correction is needed. A correction is not specified by "Standard Methods."

To determine the endpoint correction for any individual observer, a sample of unchlorinated sewage should be carried through the prescribed test. In the absence of any chlorine, the amount of iodine required in the titration should be stoichiometrically equal to the thiosulfate solution added with the KI and buffer. Instead, an excess of from 0.1 to 0.5 ml of 0.0282 N

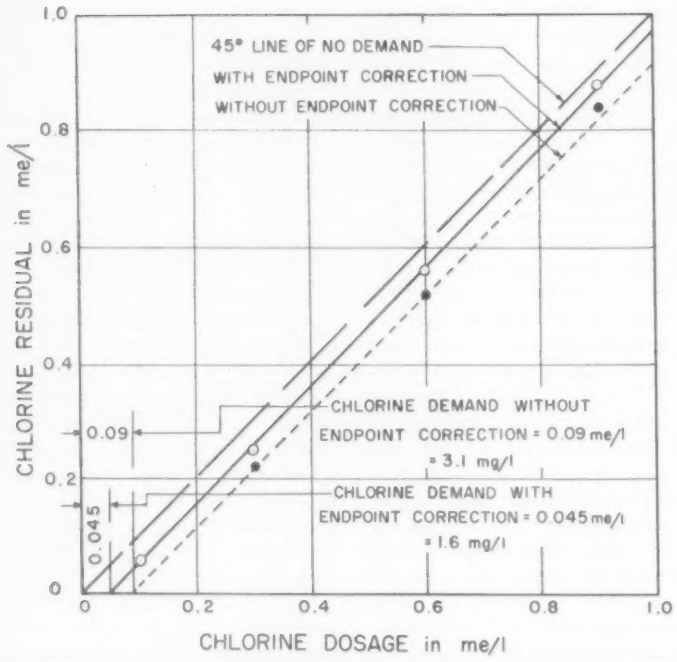

FIGURE 4.—Effect of endpoint correction on the determination of residual chlorine and chlorine demand (Pasadena sewage, 15-min contact).

iodine will be needed to produce a determinable blue color, depending on the observer.

An example of the effect of this endpoint correction is shown in Figure 4. Here, the endpoint correction was 0.16 ml of 0.025 N iodine solution. Application of the correction changed the indicated chlorine demand from 3.1 to 1.6 mg/l, based on a 15-min contact. When the initial demand is completed, the residual increases with higher dosages approximately at a 1:1 ratio, as ammonia is being converted to monochloramine.

The chlorine demand of fresh, settled Pasadena sewage, as measured by the acid starch-iodide method is very low—generally less than 3 mg/l. This sewage is taken from steep sewers in which there is abundant aeration, and is almost wholly of domestic origin. As a consequence, it contains few reducing substances such as sulfides, sulfites, and nitrites. It does, however, contain 15 to 30 mg/l of ammonia nitrogen. Thus, chlorine added to this fresh sewage is not consumed by a large inorganic chlorine demand but is taken up immediately by the ammonia to form monochloramine and organic chloramines. In the form of chloramine it is apparently quite inactive toward other organic matter during the 15-min contact. Or, perhaps, some of the chlorine actually combines with organic matter without being reduced in the process, and is not irretrievably lost. Thiosulfate in acid-KI solution may be strong enough as a reducing agent to pry this chlorine away from its temporary union with organic matter.

The foregoing findings and hypotheses are significant in this investigation, for they indicate that most of the chlorine is tied up as monochloramine or organic chloramine, and

that it remains in this form for an appreciable period. In fresh sewage, only a small amount of the chlorine is reduced to chloride or bound irretrievably with organic matter. Thus, most of the chlorine will remain available for bactericidal action; but unfortunately, it will be in the form of monochloramine which is a slow-acting lethal agent at normal temperatures. Two courses of action are indicated: either to provide a detention period long enough to allow monochloramine to do the necessary job, or to accelerate the action by chemical or physical means.

Chemistry of Bromine in Water and Sewage

Bromine is highly soluble in water and hydrolyzes as follows:

$$Br_2 + H_2O \rightleftharpoons HOBr + H^+ + Br^- \quad (20)$$

According to Wyss and Stockton (7), the equilibrium constant for this reaction is 5.9×10^{-9}. Below pH 4, more than half of the bromine remains as Br_2; but at pH 7 and above, almost all of it is hydrolyzed to HOBr.

The hypobromous acid dissociates partially into hypobromite as follows:

$$HOBr \rightleftharpoons H^+ + OBr^- \quad (21)$$

where

$$\frac{[H^+][OBr^-]}{[HOBr]} = K \quad (22)$$

According to Wyss and Stockton (7), $K = 1 \times 10^{-9}$; but Skrabal (8) gives $K = 2 \times 10^{-11}$ at 25°C, although he indicates that this value is tentative and subject to confirmation. On the basis of $K = 1 \times 10^{-9}$, almost all of the HOBr is undissociated at pH 7 and lower. At pH 8, about 10 per cent is dissociated and at pH 9, 50 per cent is converted to OBr^-. With Skrabal's constant, the HOBr remains undissociated at higher pH values. For the pH values normally encountered in natural water, either constant shows that almost all of the bromine exists as hypobromous acid.

In brominated sewage, the presence of 1 to 3 me/l of ammonia might be expected to produce bromamines. This study, however, did not uncover the reactions or constants governing such formation. Wyss and Stockton (7) state that "low concentrations of ammonia seriously impair the stability of bromine and consequently make it difficult to determine the germicidal action. At higher concentrations of ammonia (25 times as much ammonia as bromines) stable bromamines are formed which have germicidal activity equal to that of bromine in the absence of ammonia." Hypotheses relative to the formation and decomposition of bromamines are presented below in the discussion of residual curves.

Chemistry of Iodine in Water and Sewage

Iodine is almost insoluble in pure water, but it dissolves in the presence of potassium iodide to form the tri-iodide ion. When the solution is prepared at pH 6 or below, the hydrolysis of I_2 to HOI and the subsequent dissociation of HOI to OI^-, as described later, are suppressed. Then the reaction

$$I^- + I_2 \rightleftharpoons I_3^- \quad (23)$$

is in equilibrium such that

$$\frac{[I_2][I^-]}{[I_3^-]} = K = 1.4 \times 10^{-3} \text{ at } 25°C \quad (24)$$

according to McAlpine (9). At high concentrations of iodide the foregoing reaction is driven to the right, causing more iodine to be tied up as tri-iodide. Thus when $[I^-]$ is 0.1 mols per liter, corresponding to 12,900 mg/l of iodide, the ratio of $[I_2]$ to $[I_3^-]$ is only 1.4×10^{-2}, indicating that over 98 per cent of the iodine exists as tri-iodide. When this concentrated solution is diluted to 10^{-4} mols per liter or 12.65

mg/l of iodide, over 90 per cent of the iodine will be in the form of I_2. As a consequence, it is possible to prepare and store concentrated solutions of iodine in the form of tri-iodide; but when dosed into water these solutions release elemental iodine.

In dilute aqueous solution, iodine hydrolyzes to hypoiodous acid:

$$I_2 + H_2O \rightleftharpoons HOI + H^+ + I^- \quad (25)$$

for which $K = 3 \times 10^{-13}$ at 25°C, according to Skrabal (10). Hence, at pH 7 and an iodine dosage of 2 me/l, only about 5.3 per cent of the iodine is hydrolyzed and at 0.2 me/l only about 16 per cent exists as HOI. At pH 8 and a dosage of 0.2 me/l, about 42 per cent of the iodine is converted to hypoiodous acid. Dissociation in accordance with the formula

$$HOI \rightleftharpoons H^+ + OI^- \quad (26)$$

is governed by $K = 4.5 \times 10^{-13}$ according to Skrabal (10). Hence, at pH 10 or below, practically none of the HOI dissociates. At the pH values normally encountered in water, therefore, most of the iodine remains as I_2 and what little HOI is formed does not dissociate.

In iodinated sewage, the presence of 1 to 3 me/l of ammonia may be expected to produce iodamines. McAlpine (9) suggests the following reaction and equilibrium relationship:

$$2NH_3 + I_2 \rightleftharpoons NH_2I + NH_4^+ + I^- \quad (27)$$

$$\frac{[NH_2I][NH_4^+][I^-]}{[I_2][NH_3]} = K \quad (28)$$

His values for K range from 1.2 to 2.6, the average being 1.8.

Consider a sewage containing 2 me/l of ammonia, with a pH of 8. If this sewage is dosed with 0.3 me/l of iodine in excess of the iodine demand, Equation 28 indicates that about 75 per cent of the iodine will remain as I_2. At a dosage of 0.8 me/l in excess of the iodine demand, about 85 per cent of the iodine remains as I_2. For pH values below 8, even less of the iodine is converted to iodamine. Thus, while some monoiodamine will be formed in iodinated sewage of common ammonia content, most of the iodine will remain in the elemental state.

Comparison of Residual Concentrations

In the experimental work of this project, residual concentrations of bromine or iodine were determined by the acid starch-iodide method, as described previously for residual chlorine. While the reaction between thiosulfate and residual bromine or chlorine is supposedly not as stoichiometric as that with iodine, this work has shown that the results obtained even in the presence of sewage were quite precise. As described for chlorine, it is essential to determine a personal endpoint correction because the beginning of the iodine-starch reaction is difficult to distinguish in sewage.

Using this method, samples of settled Pasadena sewage were dosed with increasing amounts of chlorine, bromine, or iodine and residuals were determined. Two sets of results are presented in Figures 5 and 6. Several other samples were tested and the results were comparable.

An initial dosage is required before any residual can be measured at the end of the contact period. Above this dose, the residuals tend to increase linearly until the reaction products begin to decompose. The halogen demand may be defined as the dose required to produce a definite residual, after a standard time. The halogen demands for the two tests presented in Figures 5 and 6 are shown in Table I, both as milliequivalents per liter and as milligrams per liter.

This tabulation shows that bromine and especially iodine are more reactive initially than chlorine. This reactivity may take two forms: (*a*) bromine and iodine may be more readily converted

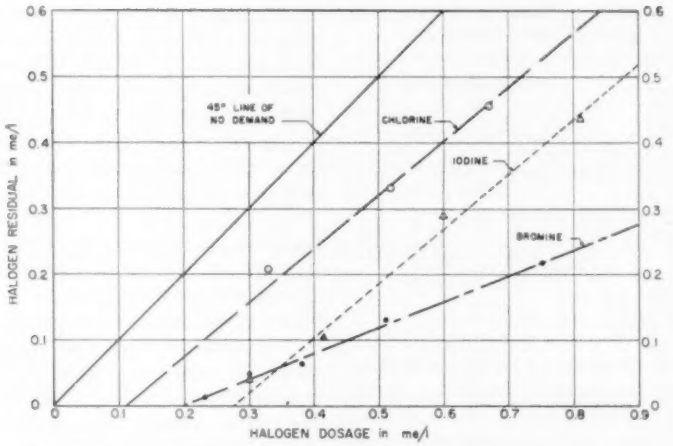

FIGURE 5.—Halogen residuals for settled Pasadena sewage for one day using 15-min contact (slope of chlorine line controlled by points beyond the scale of this plot).

to halides by reducing substances in the sewage, or (*b*) they may be bound up more completely with organic matter in irreversible reactions. The first supposition is unlikely inasmuch as the half-cell potential of chlorine is greater (negatively) than that of bromine, which in turn is greater than that of iodine. The second hypothesis is probable if it is considered that bromine or iodine bound up with organic matter will not react with thiosulfate as readily as similarly bound chlorine. Thus, when brominated sewage is poured into

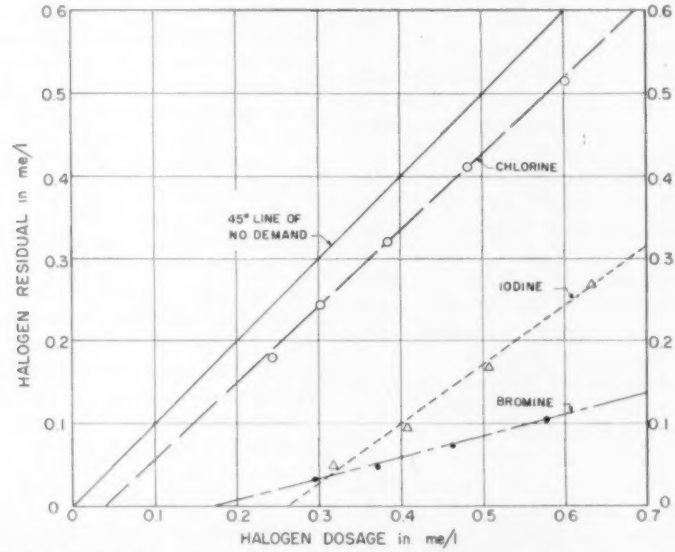

FIGURE 6.—Halogen residuals for settled Pasadena sewage for a second day using 15-min contact.

TABLE I.—Halogen Demands in Sewage for Two Separate Tests

Halogen	Halogen Demand			
	me/l		mg/l	
	Test 1*	Test 2†	Test 1*	Test 2†
Chlorine	0.11	0.04	3.9	1.4
Bromine	0.20	0.17	16.0	13.6
Iodine	0.28	0.26	35.5	33.0

* See Figure 5.
† See Figure 6.

a flask containing an excess of thiosulfate, the free bromine and bromamines probably react quickly with the thiosulfate, but the bromo-organic compounds are not as susceptible as chloro-organics to the reducing action of the thiosulfate. Molecule for molecule, therefore, bromine and iodine form more irreversible reactions with sewage than does chlorine, as shown by milliequivalents per liter. On a weight basis, the differences in halogen demand are much more apparent. Thus, in Figure 5, the iodine demand expressed in milligrams per liter is almost ten times the chlorine demand.

To determine to what extent the high initial iodine demand was attributable to inorganic oxidizable substances such as sulfides, samples of sewage were prechlorinated to satisfy the chlorine demand. Presumably this pretreatment was sufficient to oxidize any reduced compounds. These tests, however, indicated that prechlorination did not significantly diminish the iodine demand. It is apparent, therefore, that most of the iodine demand is caused by organic substances that do not react with chlorine.

The slopes of the residual curves, as shown in the two tests represented in Figures 5 and 6, are 0.82 and 0.92 for chlorine, 0.39 and 0.26 for bromine, and 0.83 and 0.72 for iodine. For no demand whatsoever, or for no demand after the initial demand has been satisfied, the slope of the residual line should be 1.0. With chlorine and even with iodine the slopes shown above are close to 1.0; but for bromine the slope is much less. This observation might indicate that some of the iodine is quickly bound up by ammonia to form iodamines, which in turn will react with thiosulfate and hence be reported as residual iodine. Free iodine and the iodamines, like chloramines, apparently do not react rapidly with organic matter after the initial demand is satisfied.

As the dosage of bromine increases, on the other hand, the residuals do not rise correspondingly. This phenomenon may indicate that bromine continues to react irreversibly with organic matter as the concentration increases; or more likely, it may be the result of the formation and rapid decomposition of bromamines. As postulated by Morris *et al.* (3), the breakpoint in chlorine-ammonia reactions is attributable to the oxidation of dichloramine, and this decomposition is not possible until significant concentrations of $NHCl_2$ are formed, i.e., above $Z = 1.0$ in Figure 2. With a bromine-ammonia system, monobromamine may be susceptible to ready oxidation and begin to decompose almost as soon as it is formed. The residual curves in Figures 5 and 6 were taken after a 15-min contact period. After a longer exposure, the bromine curves may have been still flatter.

Whatever the reason, bromine residuals at high dosages (i.e., over 0.5 me/l) are much lower than chlorine or iodine residuals. From this observation it might be inferred that high dosages of bromine are not as bactericidal as corresponding dosages of chlorine or iodine. This inference is borne out by the disinfection curves described later.

Summary

The hydrolysis and dissociation of chlorine, bromine, and iodine in water are reviewed and a chart is presented

to show the relative concentrations of ammonia, monochloramine, and dichloramine at various molar ratios of chlorine to ammonia. The formation and decomposition of halogen amines are discussed. Curves are shown to represent the breakpoint reaction in terms of pH as well as chlorine residual.

In the acid starch-iodide method for determining residual concentrations of halogens in sewage, an endpoint correction is needed. A method for determining this correction is described.

When domestic sewage is chlorinated at conventional dosages, virtually all of the residual chlorine exists as monochloramine, which is quite stable. When it is iodinated at comparable milliequivalent dosages, most of the residual iodine is in the elemental state, although some iodamine is formed. Both states appear to be relatively stable.

When bromine is used for the halogen dose, almost all of the residual may be hypobromous acid. A study of the residual curve in comparison with that for chlorine or iodine for the same sewage leads to the hypothesis that bromamines may be formed, but that they also decompose rapidly.

COLICIDAL EFFECTIVENESS

With the chemical considerations given in the foregoing as guidelines, bacteriological tests were conducted to determine the relative effectiveness of the three halogens in reducing the coliform density of settled sewage. Experiments were divided into two major categories to measure the effect of (*a*) time of contact and (*b*) concentration. Further tests were conducted on the combined actions of halogenation and heat, but they were not sufficiently definitive to warrant publication. The tests described herein were run at ambient sewage and laboratory temperatures, i.e., 18 to 22°C.

Experimental Procedures

The characteristics of the sewage used for these experiments were presented by McKee and McLaughlin (11) and McKee *et al.* (12), and the methods for applying halogens and measuring their residual concentrations were as described earlier in this paper. For the bacterial tests, samples of settled sewage were treated with varying dosages of chlorine, bromine, or iodine, stirred gently but intermittently for 15 min, dehalogenated with an excess of sodium sulfite or sodium thiosulfate, and then assayed immediately for coliform density.

MPN analyses were performed in accordance with "Standard Methods" (5) using serial dilutions and duplicate tubes of lactose broth as the presumptive medium. Previous experience (11)(12) had indicated that the membrane filter technique was not applicable to chlorinated sewage. Eosin-methylene-blue (EMB) agar was selected as the confirmatory medium in order that a visual inspection of the colonies might indicate whether the transferred organisms were definitely fecal or perhaps of soil origin. This appearance did not affect the results, for growth of any nature on the EMB plate was considered to be a positive test for coliforms. Bacterial assay was conducted routinely through the confirmed test, but not the completed test, which is seldom used in sewage analyses (5). In the few completed tests checked during this experimentation, the confirmed tests always showed positive completion.

Time of Contact

The "chlorine demand" of a water or waste is defined (5) as the difference between the amount of chlorine applied and the amount of total available residual chlorine (free and combined) remaining at the end of the contact period. The "chlorine requirement" is defined (5) as the

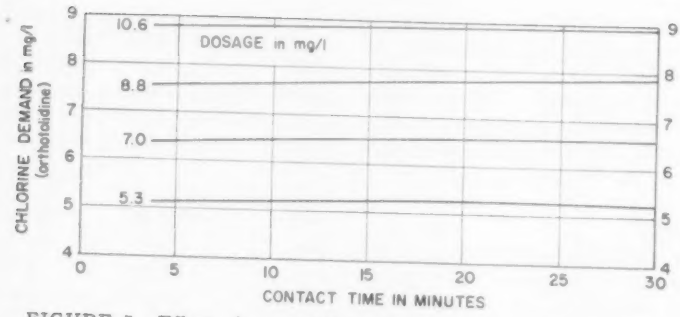

FIGURE 7.—Effect of contact time on chlorine demand at various dosages in settled sewage (after Eliassen and Krieger—Ref. 13).

amount of chlorine in milligrams per liter which must be added to sewage to produce a chlorine residual of such strength that, after a definite contact time, the effluent will show a desired coliform density, or will meet the requirements of some other objective. Both the contact time and the amount of chlorine can be varied to produce the desired result. In reporting chlorine demand or chlorine requirement, it is essential that the contact time be specified, inasmuch as neither of the definitions includes this important factor. The chlorine demand will increase but the chlorine requirement will decrease as the contact period is lengthened.

The effect of contact time and chlorine dosage on the chlorine demand of settled sewage was reported by Eliassen and Krieger (13). The data in their paper have been reorganized and plotted herein as Figure 7, showing the chlorine demand for each initial dosage at various contact periods. It is important to note that orthotolidine residuals (OT) were used in this work; consequently, it is not surprising that the demand increased rapidly as the dosage increased. Had the acid starch-iodide back-titration method been used, the difference in demand for varying dosages would not have been so pronounced.

The important thing to recognize in Figure 7 is the slight but gradual increase in chlorine demand as the contact time is lengthened. This increase is attributable to the slow reduction of monochloramine by organic products of decomposition and to the irreversible chemical union of monochloramine or hypocholorous acid with organic substances. The fact that the

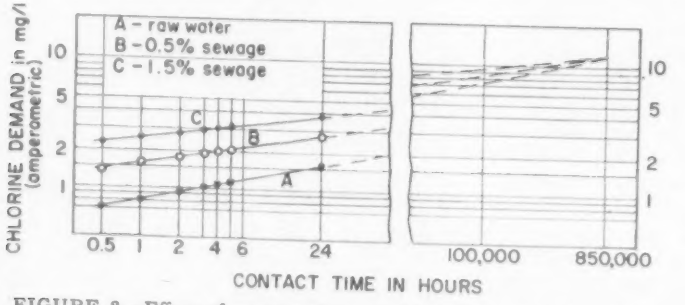

FIGURE 8.—Effect of contact time on chlorine demand of polluted water (after Feben and Taras—Ref. 14).

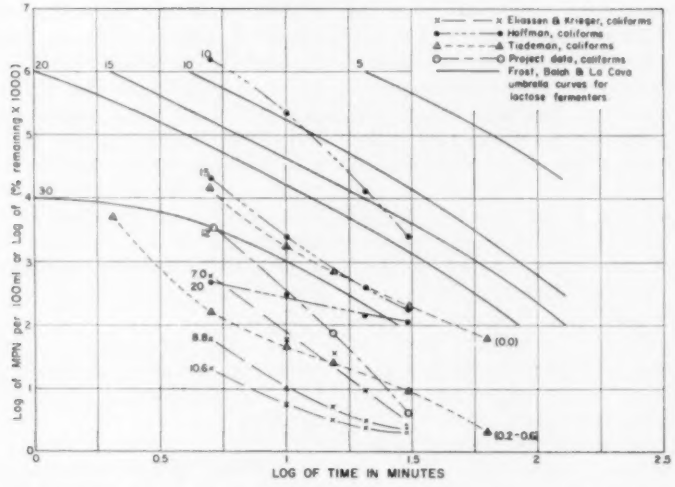

FIGURE 9.—Effect of chlorine contact time on the survival of bacteria. (Figures at end of curves give chlorine dosages in milligrams per liter, or, if in parentheses, residuals.)

demand increases so slowly with time, and conversely, that the residual chlorine persists so long, favors the use of long contact periods.

Feben and Taras (14) made a similar study, except that the chlorine demand was measured amperometrically and diluted sewage (0.5- to 1.5-per cent) was employed. The results of their investigation, shown by Figure 8, confirm Eliassen and Krieger's observation that the chlorine demand increases slowly during the contact period. Feben and Taras formulated their results as follows:

$$\frac{D_t}{D_1} = t^{0.18-0.17 \log D_1} \quad \ldots\ldots (29)$$

where D_1 is the chlorine consumed (i.e., the demand) after one hour and D_t is the chlorine consumed after t hours. Thus, if the chlorine consumption were 6 mg/l after 1 hr, the formula indicates that it would be about 6.7 mg/l after 10 hr—a very slow increase. For a 10-min contact, the corresponding chlorine consumption would be 5.5 mg/l. It is evident, therefore, that the flat slopes of the chlorine demand curves of Eliassen and Krieger agree with those of Feben and Taras, despite the fact that the former were based on settled sewage, while the latter were derived from 0.5- to 1.5-per cent dilutions of sewage.

The effect of contact time on the chlorine requirement, i.e., on the coliform density, is quite a different matter. The decrease in bacterial numbers with time, as a result of unfavorable environmental conditions, is sometimes formulated by Chick's Law:

$$\log N_o - \log N = kt \quad \ldots\ldots (30)$$

where N_o is the initial number of organisms, N the number after time t, and k is a constant varying with the nature and concentration of the lethal agent.

To investigate the relationship between coliform density and time in a chlorinated sewage, the results reported by several investigators have been plotted in Figure 9. Frost *et al.* (15) studied survival of lactose fermenters as a function of time and

drew "umbrella" curves to cover all points. These investigators did not confirm the positive lactose curves, and consequently, many spore-forming noncoliform bacteria are included in the numbers surviving chlorination. Results of this work are shown as solid lines in Figure 9.

Eliassen and Krieger (13) used the confirmed test (BGB broth) to find the effect of contact time on colicidal action. Similar data for Tiedeman's classical study (16), Hoffman's experiments (17), and for project work are also shown in Figure 9. In this plot the abscissa is the logarithm of the time. When these data are plotted on semi-log paper, the resulting lines are all curvilinear, with steep slopes at low times and diminishing slopes for increased times. Hence, Chick's Law does not appear to hold. With a double-log plot, however, the lines of best fit closely approximate straight lines in most cases, some being slightly concave and others slightly convex.

For a straight line on log-log paper, it can be shown that

$$\frac{N_t}{N_a} = \left(\frac{t}{a}\right)^m \quad \ldots\ldots\ldots (31)$$

where N_t is the number of organisms surviving at time t, N_a is the number at an initial time a, and m is the slope of the straight line (a negative value in this instance). If $a = 1$ min,

$$\frac{N_t}{N_1} = t^m \quad \ldots\ldots\ldots (32)$$

For the data reproduced in Figure 9, the values of m are approximately as shown in Table II.

These values range from -0.8 to -3.8, for which the mean might be taken at about -2.2, or more conservatively, at about -2. Based on the data of Eliassen and Krieger (13) and Hoffman (17), it appears that the slopes are steeper for the lower chlorine dosages, within the time periods of the experiment. Expressed otherwise, small chlorine dosages (beyond satisfaction of the demand) may be as effective as larger dosages, provided that the period of contact is extended sufficiently.

Table II.—Values of m from Various Investigators

Investigators	m (approx.)
Frost *et al.* (15)	−2.0 to −2.4
Tiedeman (16)	−2.1 to −2.3
C.I.T. project	−3.8
Eliassen and Krieger (13)	−1.3 to −3.0
Hoffman (17)	−0.8 to −3.5

For the remaining experimental work reported here, a contact time of 15 min has been used unless otherwise specified.

Effect of Chlorine Dosage

Tests were conducted to determine the effect of chlorine dosage on coliform concentrations. The results can be plotted in four different ways, with the logarithm of the coliform density as ordinate against (*a*) chlorine dosage, (*b*) chlorine residual, (*c*) the difference between the chlorine dosage and the chlorine demand, a parameter that is not always equal to the residual, and (*d*) the ratio of chlorine dosage to demand, all as abscissae.

With the fresh sewage used in this project, there is no major difference in the general appearance of all four plots. Indeed, about 99-per cent disinfection is accomplished before a residual can be measured. For this reason, it is most logical to plot halogen dosage as the abscissa, rather than to plot the residual or a function of the residual. Figure 10 shows the logarithm of the coliform density as a function of the chlorine dosage in milliequivalents per liter.

For each test, there appears to be a straight-line relationship up to a dosage of about 0.25 me/l, or perhaps even to about 0.35 me/l. In this region, if N_0 is the initial coliform concentration per 100 ml and N_x the concentration after minutes of contact with a dosage x in milliequivalents per liter,

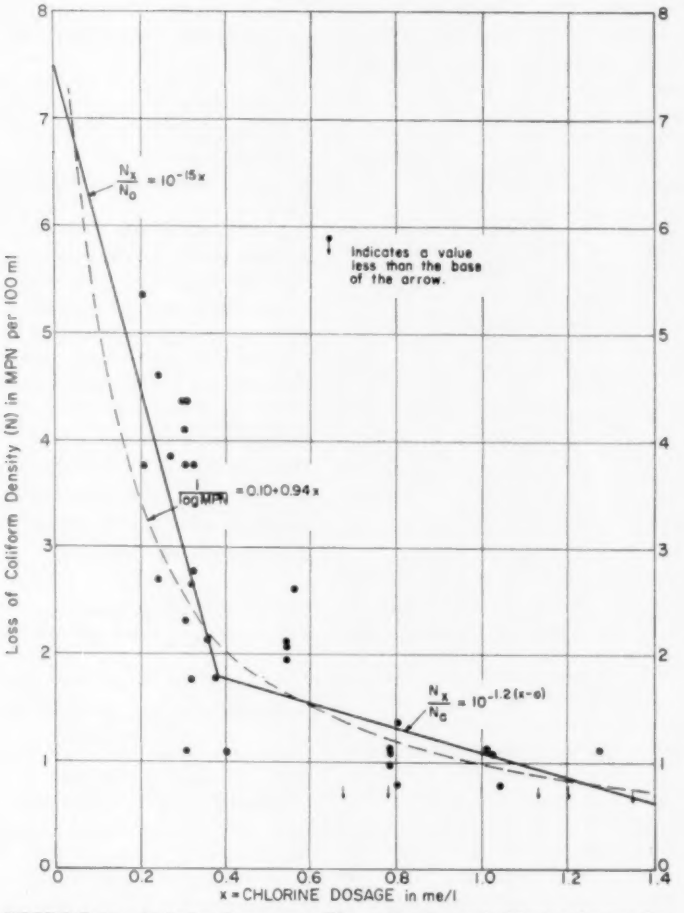

FIGURE 10.—Relation between coliform density and chlorine dosage for settled Pasadena sewage (15-min contact).

then

$$\frac{N_x}{N_o} = 10^{-15x} \quad \ldots\ldots\ldots (33)$$

as x varies from zero to 0.25 or 0.35 me/l. The exponential coefficient (-15) is the negative slope of the straight line. The rapid kill in this region may relate to the most susceptible coliforms, probably those which are not imbedded deeply in solids.

There may be another straight-line relationship for hardier (or protected) organisms, for dosages in excess of about 0.5 me/l. Here

$$\frac{N_x}{N_a} = 10^{-1.2(x-a)} \quad \ldots\ldots\ldots (34)$$

where N_a is the coliform concentration at a reference dosage a. The exponential coefficient represents a much flatter slope than that which occurs for smaller dosages.

Instead of two straight lines, the over-all relationship may be represented by a curve, as suggested by Eliassen and Krieger (13) and used

by Hess *et al.* (18). Plotting the log of coliforms against residual chlorine (OT) for a 15-min contact period, Eliassen and Krieger derived the relationship:

$$y = \frac{1}{\log N_z} = 0.28 + 1.04z = a + bz \quad . . (35)$$

where z is the residual chlorine in milligrams per liter and a and b are constants. This is a straight-line relationship for which their plotted points had a coefficient of correlation r equal to 0.45. Hess *et al.* (18) used this relationship for the chlorinated effluents of 15 treatment plants (including two secondary treatment plants), with variable contact times. Their values of a ranged from 0.194 to 0.441 and of b from 0.129 to 0.587. Coefficients of correlation varied from 0.410 to 0.908 for the 15 plants.

Using the same approach for the project data, Figure 11 shows the reciprocal of log MPN per 100 ml plotted against dosage x in milliequivalents per liter. The corresponding formula is

$$y = \frac{1}{\log \text{MPN}} = 0.10 + 0.94x \quad . . (36)$$

and the coefficient of correlation r is 0.81.

Returning to the formulations based on two straight-line relationships, the cost of additional chlorine for the flatter curve may be compared with the cost of a longer detention period to achieve the same effect. Suppose that chlorination for 15 min with a dosage of 15 mg/l reduces the coliform concentration to 100 per 100 ml. Suppose also that it is necessary further to decrease the coliform density by a factor of 10; then the relationship for increased dosage will be

$$\frac{N_x}{N_a} = 10^{-1.2(x-a)} = \frac{1}{10} \quad . . . (37)$$

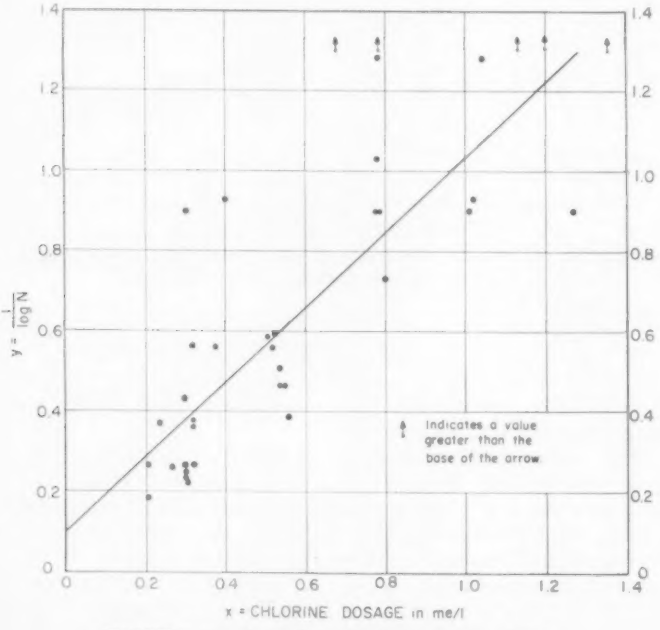

FIGURE 11.—A straight-line formulation of the coliform-dosage relationship.

Hence $(x - a) = 0.833$ me/l, or 29.6 mg/l, or 247 lb/mil gal. At 6¢/lb for chlorine, the additional cost would be $14.80 per million gallons.

To achieve the same effect by increased detention period, based on Equation 31, let it be assumed conservatively that the exponent m is -2.0. Then

$$\frac{N_t}{N_a} = \left(\frac{a}{t}\right)^2 = \frac{1}{10} \quad \ldots\ldots (38)$$

hence $\frac{t}{a} = \sqrt{10} = 3.16$. If the original detention period a was 15 min, then an extension to 48 min, or say one hour, would suffice. For a 5.0-mgd plant, current construction costs with 30-yr bonds at 3-per cent interest indicate that one extra hour of detention would cost about $0.70/mil gal, or about 5 per cent of the cost of comparable additional chlorine. Certainly, then, the provision of longer chlorine contact appears to be less costly than higher chlorine dosages.

Review of Disinfection by Bromine and Iodine

The bactericidal action of free iodine at two temperatures (2 and 25° C) and at two pH values (7.5 and 9.15) was investigated by Chambers *et al.* (19). Using 12 species and strains of *Salmonella*, *Shigella*, and coliform bacteria, these investigators achieved 100-per cent kill in one minute of exposure at iodine concentrations of 1.0 mg/l or less at 25°C and pH 7.5. When the pH was raised to 9.5, dosages as high as 1.55 mg/l were required to kill 100 per cent of some organisms. From these results and the hydrolysis and dissociation constants described earlier, it might be hypothesized that hypoiodous acid, formed at higher pH values, is less bactericidal than free iodine.

Decreasing the temperature to 2 to 5°C caused a fourfold increase in the iodine concentration needed for 100-per cent kill in one minute. Two of the three *Shigella* strains studied were somewhat more resistant than the strains of *E. coli* used. *S. typhosa* was the least resistant to iodine and *Shigella sonnci* the most resistant of all cultures studied. In general, the bactericidal action of iodine resembled that of chlorine with respect to temperature and pH, but higher concentrations of iodine were required to produce comparable kills under similar conditions (19). These findings corroborate the results of this investigation, as described later.

In contrast, Beckwith and Moser (20) found that bromine and iodine were more effective than chlorine (on a weight basis) against coliforms in tap water. Bromine was slightly better than iodine. Gershenfeld and Palisi (21) reported that iodine was slightly more effective than chlorine against *S. typhosa* and *St. aureus*. According to Tanner and Pitner (22), bromine concentrations of less than 0.25 mg/l killed *St. aureus*, *St. albus*, *E. coli*, and *S. typhosa* in 15 to 30 sec in water at room temperature. Slightly higher concentrations killed yeasts, but mold spores required 5 to 30 mg/l, and spores of aerobic bacteria required 100 to 450 mg/l at pH 6.8 to 7.2. McCarthy (23) reported that bromine was not as effective as chlorine for water disinfection, especially when organic matter was present; hence, for sewage, bromination would not be recommended.

In contrast again, Symon (24) maintained that bromine has the same disinfecting power as iodine and that each is 10 times more effective than chlorine against microorganisms in water. According to Elliker (25), in solutions free of organic matter, chlorine is the most effective bactericidal halogen, with bromine next, and iodine last.

Toward higher organisms and especially toward cysts and spores, iodine and bromine may have some

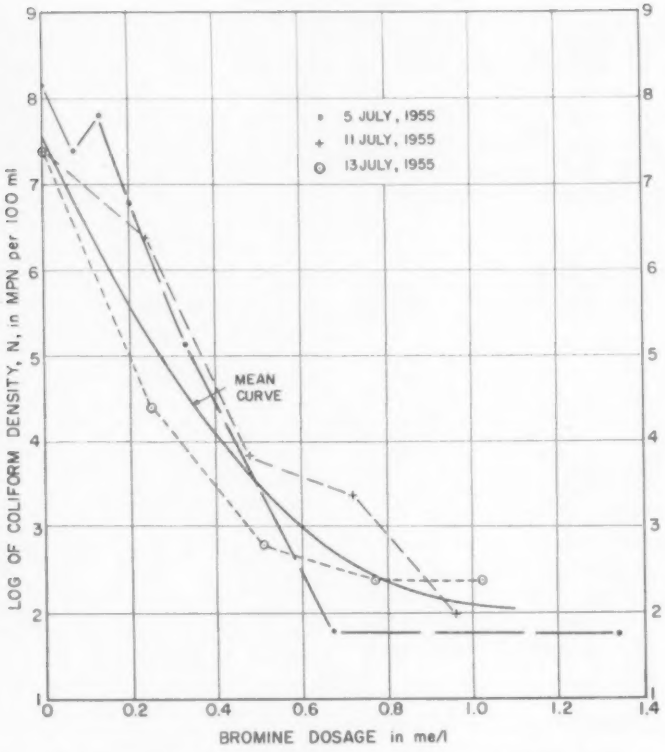

FIGURE 12.—Relation between coliform density and bromine dosage for settled Pasadena sewage (15-min contact).

advantages over chlorine. Chang and Morris (26) indicated that iodine concentrations of 5 to 10 mg/l were effective within 10 min at room temperature against all types of water-borne pathogens, including bacteria, amoebic cysts, cercariae, leptospira, and viruses. Water of high organic content may exhibit sufficient iodine demand to require increased dosage for satisfactory disinfection. At low temperatures, germicidal action is slower, so that longer contact times are necessary. The germicidal action of iodine appears to be less dependent than that of chlorine on pH, temperature, and time of contact. Moreover, nitrogenous impurities do not impair the effectiveness of the iodine. A dosage of 8 mg/l of iodine is reported (26) to give complete destructions of 30 cysts per ml within 10 min in most natural waters, except for those near 0°C or those with iodine demands greater than 4 mg/l. This iodine dosage also reduces 10^8 enteric bacteria per 100 ml to less than 5 per 100 ml within 10 min.

Toward cysts of *E. histolytica*, Chang and Baxter (27) found that the time rate of reduction followed Chick's Law when aqueous suspensions of 50, 250, and 500 cysts/ml were treated with 10 mg/l of iodine. Over 99.9 per cent of the cysts were inactivated by this dosage in 6 min. *Leptospira icterohemorrhagiae* is much less resistant to iodine and to other dis-

infectants than are most of the non-spore-forming bacteria. Chang *et al.* (28) reported that iodine destroyed 100 per cent of the leptospira in water containing over 1 million organisms per millilter in 1 min when the residual iodine was 5 mg/l, and in 10 min when the residual was 0.7 mg/l.

According to Green and Stumpf (29), the germicidal action of iodine is attributable to the inactivation within a cell of an enzyme that controls glucose oxidation. They suggest that iodine irreversibly inactivates zymohexase, rather than triosephosphoric dehydrogenase as in the case of chlorine. Wyss and Strandskov (30) report that, toward spores of *B. metiens*, the germicidal action of iodine is due mainly to the I_2 molecule, but at high pH values the presence of hypoiodous acid (HOI) has some effect also. Elliker (25) suggests that the mode of action of iodine either differs from that of chlorine compounds or that the iodine molecule is less able than HOCl to penetrate to the vital parts of organisms. He maintains that HOI is much less germicidal than HOCl or than I_2.

Colicidal Effectiveness of Bromine and Iodine

A series of standardized tests, similar to those described for chlorine, was conducted to determine the colicidal effectiveness of bromine and iodine in

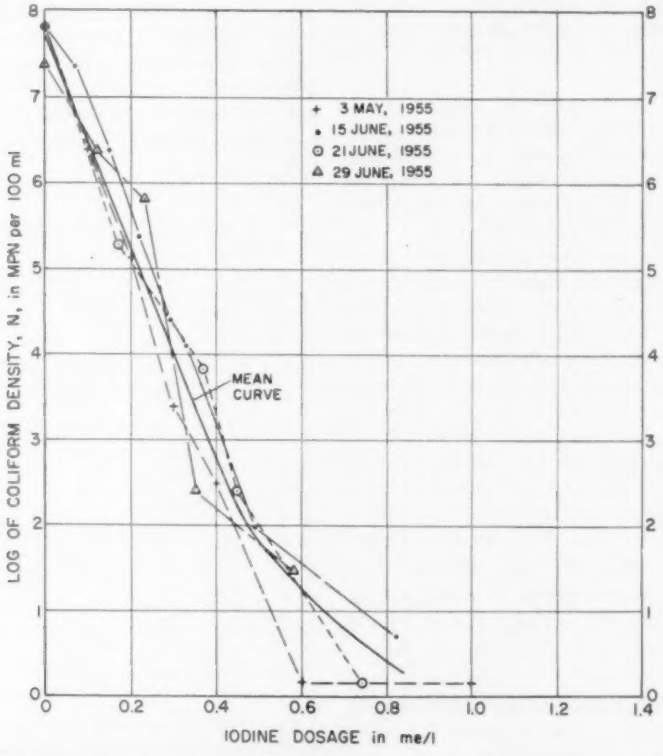

FIGURE 13.—Relation between coliform density and iodine dosage for settled Pasadena sewage (15-min contact).

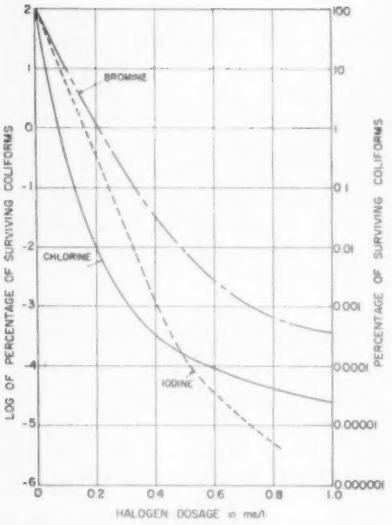

FIGURE 14.—Comparison of colicidal effectiveness of chlorine, bromine, and iodine for settled Pasadena sewage (15-min contact).

settled sewage during a 15-min contact period. The results of three experiments with bromine are presented in Figure 12 and those for four tests with iodine in Figure 13.

To compare these results with those for chlorine, all data were converted to percentages of surviving organisms (Figure 14). Small doses of chlorine (i.e., 0.1 or 0.2 me/l) are more effective than comparable doses of bromine or iodine; but above 0.5 me/l, iodine is equal to or better than chlorine. If allowance is made for the high initial iodine demand, which is about 0.2 me/l greater than the chlorine demand, Figure 15 suggests that residual iodine is more effective than residual chlorine. This conclusion is borne out by Figure 16, where the survival curves are plotted as a function of the titrated residuals.

As predicted from the chemical considerations, bromine is shown to be less effective than chlorine or iodine, especially at higher dosages. Presumably this shortcoming is due to the fact that much bromine becomes irretrievably bound up with organic matter or forms bromamines that break down rapidly; at least, it is probably not available as free bromine or bromamine for disinfection. Even when allowance is made for the initial demand (about 0.18 me/l), bromine compares unfavorably with chlorine and especially with iodine, as shown in Figure 15. In terms of the titratable residuals, however, bromine is comparable with chlorine and iodine, as shown in Figure 16. Thus, the residual bromine or bromamine is just as colicidal as the other halogen residuals—the only difficulty being that not much of the bromine dosage becomes a stable residual.

All results in Figures 12 to 16 inclusive have been plotted with halogens measured in terms of milliequivalents per liter. This procedure is useful in that milliequivalents per liter is a function of the number of molecules of each halogen, regardless of its molecular weight. These substances

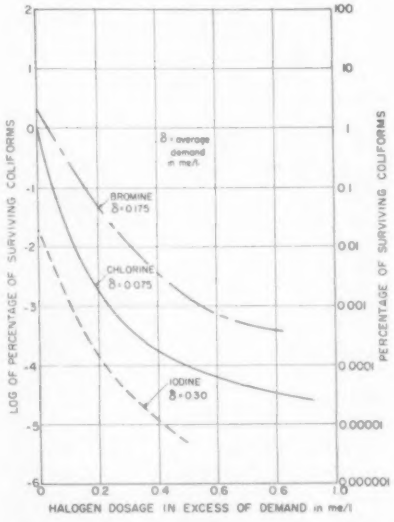
δ = average demand in me/l
BROMINE δ=0.175
CHLORINE δ=0.075
IODINE δ=0.30
LOG OF PERCENTAGE OF SURVIVING COLIFORMS
PERCENTAGE OF SURVIVING COLIFORMS
HALOGEN DOSAGE IN EXCESS OF DEMAND in me/l

FIGURE 15.—Comparison of colicidal effectiveness with halogen dosages in excess of demand for settled Pasadena sewage (15-min contact).

are purchased and handled, however, by their weight, for which Figure 17 shows a comparison. Here the superiority of chlorine is clearly evident. To achieve a 99.995-per cent kill of coliforms, about 45 mg/l of bromine or iodine will be required; but 8 mg/l of chlorine will be just as effective.

Summary and Conclusions

Molecule for molecule, residual concentrations of iodine, bromine, and chlorine, as determined by the acid-KI back-titration method, are about equally effective in colicidal action. On a dosage basis, however, and especially for small applications, chlorine is superior because much of the iodine or bromine is utilized in satisfying the halogen demand. Once the initial demand is satisfied, iodine appears to be the best disinfectant. Bromination in excess of the initial demand does not produce a high proportion of residual bromine or bromamines. Presumably such residuals are relatively unstable. Consequently, bromine is the least effective halogen at high dosage rates.

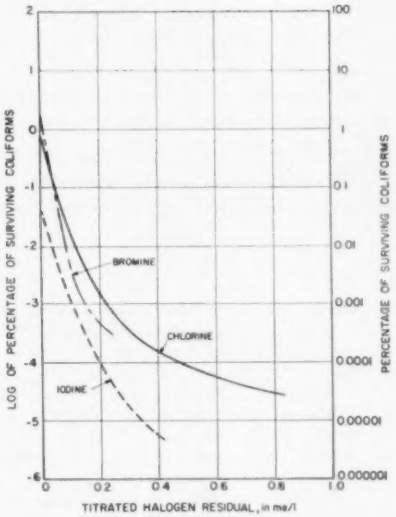

FIGURE 16.—Comparison of colicidal effectiveness in terms of halogen residuals for settled Pasadena sewage (15-min contact).

On a weight basis, chlorine is far superior to bromine or iodine owing

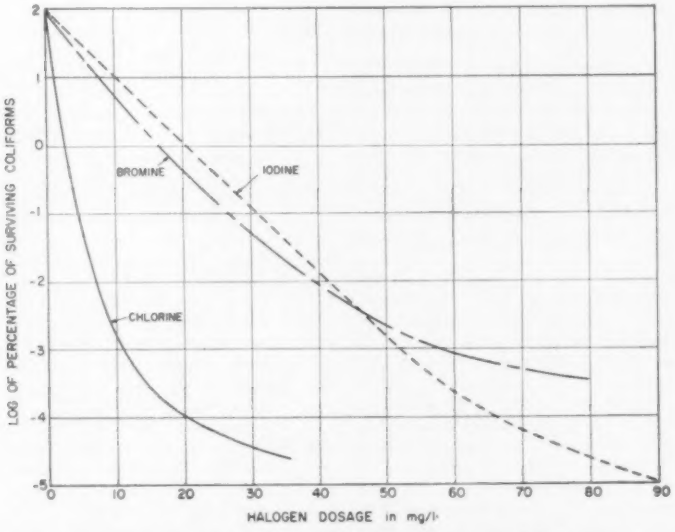

FIGURE 17.—Comparison of colicidal effectiveness of halogens on a weight basis for settled Pasadena sewage (15-min contact).

to the high molecular weights of the heavier halogens. Thus, 8 mg/l of chlorine will achieve disinfection comparable to that of 45 mg/l of bromine or iodine. Chlorine, moreover, is much less costly than other halogens. These weight and cost factors combine to exclude bromine or iodine from any practical consideration in the disinfection of sewage.

Acknowledgment

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THE 11TH EDITION OF STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER

The 11th Edition of "Standard Methods" is expected early in the fall. This is a major expansion of the 10th Edition and is again published jointly by the American Public Health Association, the American Water Works Association, and the Water Pollution Control Federation. To conform to advances in analytical techniques and in processes for water and wastewater treatment, the new volume includes many changes in specific methods plus the addition of new sections and new test procedures.

The general format is unchanged. As in previous editions, the volume contains simple procedures for the control of treatment processes as well as more complex tests for special and research investigations.

The contents are presented in nine parts, three new parts having been added as compared with the 10th Edition.

A new policy which affects the status of "Tentative" and "Standard" is outlined. The statistical discussion has been expanded and improved.

Changes in the following tests are of particular interest to those in the wastewater field: chlorides, residual chlorine, grease, nitrates, organic nitrogen, cyanides, chromium, copper, manganese, phenol, volatile acids in sludge, membrane technique for bacteria, and microscopic examinations. The three new sections are: bio-assay methods for the evaluation of acute toxicity of industrial wastes to fish, methods for radiologic examination of water and wastes, and methods for detection and isolation of iron and sulfur bacteria.

The price to members will be $8 and to others, $10.

GEOLOGIC AND HYDROLOGIC ASPECTS OF STABILIZATION PONDS

By Gerald Meyer

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Population growth, urbanization, and industrial expansion in the United States have created major waste disposal problems. The disposal of industrial radioactive wastes alone poses complex physical, chemical, and hydrologic problems to which solutions are being intensively sought. From the standpoints of good engineering, resource conservation, and health safety, a knowledge of local geology and hydrology is fundamental to disposal of wastes, particularly where these wastes are released on the land surface, in streams, or in the ground.

For the past few years scientific journals concerned with the treatment and disposal of wastewater have published numerous papers on disposal by the pond, or lagoon, method. One recent review paper (1) contains references to 79 papers on the subject. Some of these papers describe laboratory investigations of the biochemical processes that take place in the ponds, but most concern field studies of ponds in operation. Many of the articles note the possibility of ground-water pollution in the vicinity of the ponds. Although many ponds are operating satisfactorily and with no significant adverse effect on ground-water supplies, serious problems have developed in a number of instances.

Stabilization ponds have been in use in the Great Plains states for a number of years as an inexpensive and generally successful method for treating the raw sewage of small municipalities. Basically similar "oxidation" ponds have been used in the southwestern states for several decades for the secondary and tertiary treatment of sewage. Sanitary engineers in the eastern states also are recognizing stabilization ponds as an economical means of treatment and the number of these installations in the East is increasing.

Industrial waste ponds and lagoons operate in a manner similar to those treating domestic sewage, but owing to the many kinds of industrial wastes, a greater variety of stabilization and disposal processes is involved. Many industrial waste ponds rely more heavily on infiltration and evaporation to dispose of waste liquids than do sewage ponds.

Relation to Local Geology and Ground-Water Conditions

With respect to the potential effect on ground-water quality, the critical factor in the operation of the ponds is the degree of infiltration of sewage liquids through the bottom of the pond. For some installations it is assumed that the bottom of the pond is sealed by sewage solids, or bacterial plugging; for others the soil is treated to decrease its permeability. In still other installations, the rate of infiltration of water is increased artificially to reduce the volume of surface effluent and increase effective pond capacity. This practice is common for many industrial waste ponds in which infiltration is the principal manner of disposal (2) (3). By balancing inflow to the pond with discharge by infiltration and evaporation, surface effluent can be held to a minimum or eliminated.

Commonly, the bacterial count of the

effluent from the waste ponds is less than 1 per cent of the influent value (1). Water infiltrated through the bottom of a pond will have received in the pond the same purification treatment as that discharged from a surface overflow outlet. The infiltrating water is relatively low in bacteria if the

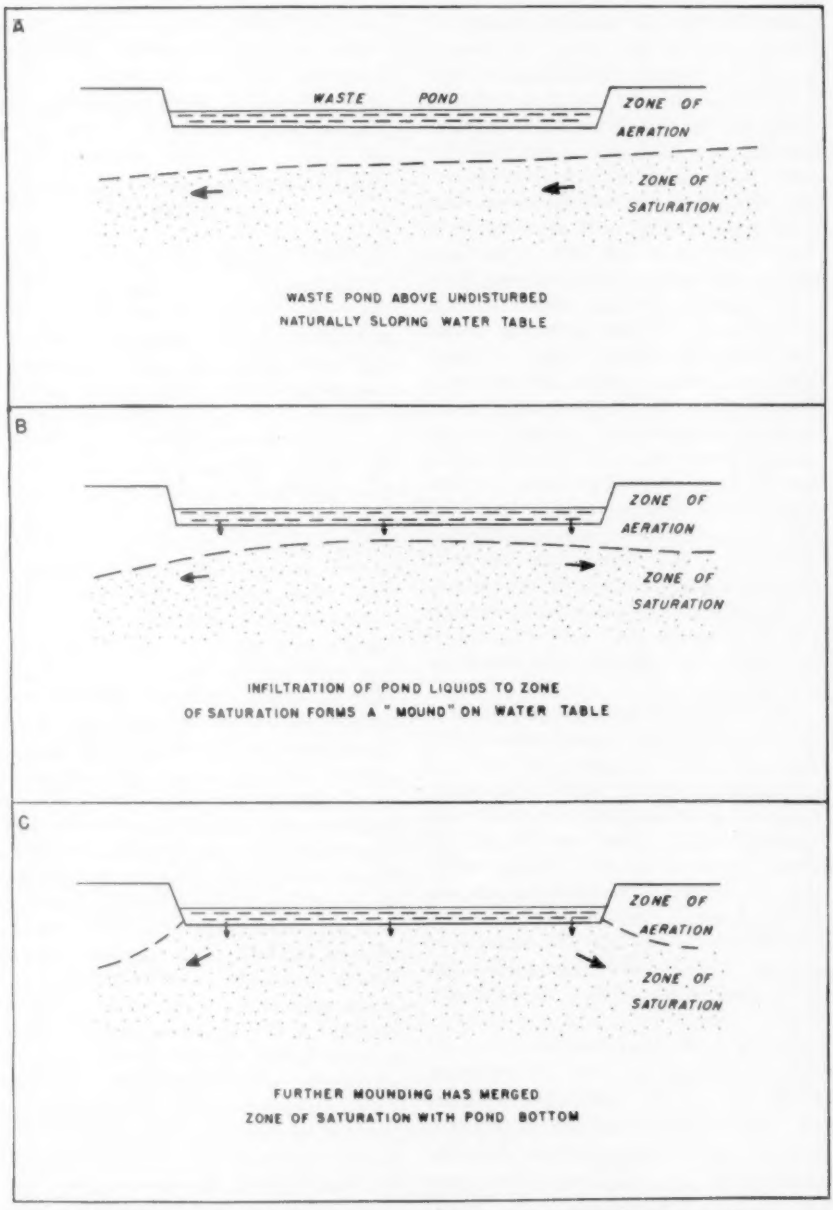
A
WASTE POND
ZONE OF AERATION
ZONE OF SATURATION
WASTE POND ABOVE UNDISTURBED NATURALLY SLOPING WATER TABLE
B
ZONE OF AERATION
ZONE OF SATURATION
INFILTRATION OF POND LIQUIDS TO ZONE OF SATURATION FORMS A "MOUND" ON WATER TABLE
C
ZONE OF AERATION
ZONE OF SATURATION
FURTHER MOUNDING HAS MERGED ZONE OF SATURATION WITH POND BOTTOM

FIGURE 1.—Hydrologic effects of infiltration to a ground-water aquifer.

stabilization processes are working properly.

If the pond lies well above the zone of saturation (Figure 1*A*), that is, above the zone in the underlying rock in which the rock pores are completely filled with water under hydrostatic pressure, there is additional sanitary protection for the aquifer. Studies have shown that percolation through as little as 10 ft of unsaturated fine sand will remove all bacteria (4). If the top of the zone of saturated rocks (the water table) is 10 ft or more below the bottom of the stabilization pond, wastewater must migrate downward through at least this much unsaturated rock before reaching the water table, and this inhibits ground-water pollution. It should be noted, however, that highly permeable gravel, fissured rock, or rock containing large solutional openings offer substantially less sanitary protection than sand and clay. Also, sealing will be less effective in these more permeable materials. Ordinarily, the bulk of the bacterial treatment takes place in the several inches of material immediately beneath the pond bottom (5), and it is also in this zone that the sealing effects are greatest.

Although rock pores above the zone of saturation may contain some water, they are filled mostly with air, and hence this shallower zone is called the zone of aeration (Figure 1*A*). Its thickness ranges from zero in marshy areas or other lowland areas, where the water table is at the land surface, to hundreds of feet in deeply incised, well-drained areas. In the central and eastern states, the water table commonly is 5 to 50 ft below the land surface.

In view of the increasing use of stabilization ponds in the densely populated central and eastern parts of the country, it is pertinent to mention that many municipalities in these areas are situated on broad alluvial flood plains of rivers. Characteristically, flood-plain deposits are irregular, lenticular deposits of clay, silt, sand, and gravel. To minimize ground-water pollution, the clay and silt areas should be favored for pond sites. On the other hand, if infiltration is an important factor in pond operation, then consideration should be given to areas underlain by the more permeable sand and gravel.

Areal Geologic and Hydrologic Considerations

Bacterial Travel

Literature pertaining to the survival and transport of bacteria in ground-water environments is scarce, but two important and interrelated factors are the permeability of the rocks through which the water must move and the velocity of ground-water movement. Stead (6) has pointed out that very few sewage bacteria are able to survive in ground-water environments; more than 99 per cent die within 2 or 3 weeks after exposure to this environment. He states that "Ground-water velocities vary but are usually in terms of not more than a few feet per day, so that travel horizontally of sewage bacteria for distances greater than a few hundred feet is extremely rare." Here again the greater effectiveness of fine-grained materials over highly permeable materials in treating or removing polluting substances should be kept in mind. There has been little research on the distance bacteria can travel through specific rock materials. Few studies have considered the nature of transport of the bacteria and the mechanisms that remove them in ground-water environments. A recent laboratory investigation by Krone, Orlob, and Hodgkinson (5) represents a substantial contribution on this problem. At present the various specifications adopted by the U. S. Public Health Service (2) and the state health agencies for safe distances for well and spring supplies

from polluting sources must be considered somewhat empirical. In general, the specified distances are average values based largely on field experience and generous tolerances.

Chemical Travel

Many industries utilize waste lagoons. Industrial wastes are the principal source of soluble inorganic waste liquids, but sewage also may yield significant quantities of these wastes. Additional chemical constituents are contributed by the stabilization processes in the pond and reactions with the soil. These inorganic liquids are not readily affected by the "filtering" effect that aquifers have on bacterial contaminants. Dilution with ground water is slow, so that heavy concentrations of chemical waste may travel distances many times greater than bacterial contaminants. The literature includes records of mineral changes in ground water traceable to disposal of sulfuric acid, phenols, detergents, chromium and fluorine compounds, and a host of other chemicals. Detergent and chloride contaminations have been reported as much as ¾ of a mile from a sewage pond (7), fluoride contamination 2 miles from industrial waste lagoons (8), and significant mineral changes 4¾ miles from garbage dumps (9).

Subsurface Investigations

The modern quantitative methods used for evaluating ground-water availability are applicable to problems of waste disposal beneath the ground surface. For many geologic settings, field measurements of the storage capacity and permeability of rocks to the accuracy necessary for pollution studies are entirely practical. This information, supplemented by additional geologic and hydrologic data, permits determination of velocities and directions of movement of ground water. As part of their investigational techniques, ground-water hydrologists now routinely utilize field aquifer tests, as well as laboratory methods, to define the hydrologic properties of aquifers, to detect hydraulic interconnection between the aquifers and streams, ponds, and other surface-water bodies, and to evaluate aquifer-boundary conditions (10) (11). For most areas the facilities required for aquifer tests are one well that can be pumped and several inexpensive observation wells or piezometers. Measurement of the water levels in these same wells, and in additional drilled ones if needed, also provides data from which maps showing the configuration of the water table may be constructed. These maps indicate approximate directions of ground-water movement and other important hydrologic features.

Subsurface geologic maps compiled from logs of wells indicate the physical nature of the ground-water reservoir in three dimensions. Surficial geologic maps are constructed by utilizing the log data and those data acquired by surface traverses.

When integrated, this information delineates the aquifers, reveals normal directions of movement of the ground water, identifies suitable sites for ponds, indicates the probable hydrologic effects of recharge from infiltrating pond liquids, and shows additional pertinent information.

Although the water table usually is similar in shape to the land surface and slopes in the same directions, this relationship does not always hold true. The exceptions may be due to some natural geohydrologic factors or to disruption by man-made installations. For waste disposal projects, prediction of directions of ground-water flow on the basis of topography is risky. Numerous examples are recorded in which the contaminated ground water moved in unanticipated directions and counter to the topography. In all three of the studies of chemical contamination cited (7) (8) (9), this was the case. Likely pond sites are often flat land, which offers no clue to the direction of

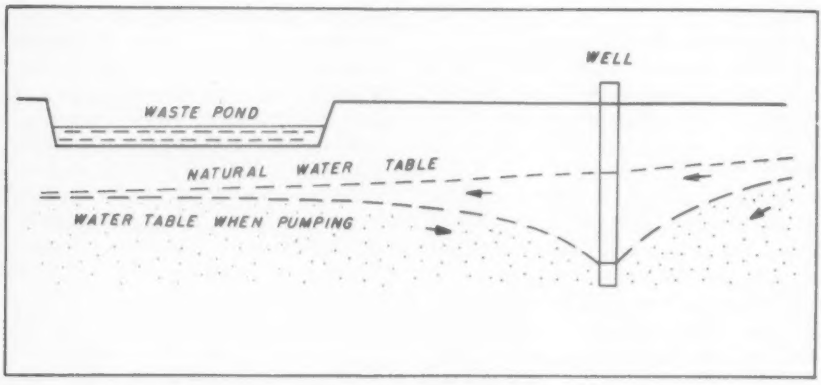

FIGURE 2.—Reversal of ground-water flow induced by well pumping.

ground-water movement. Where artesian conditions of ground-water occurrence are involved, the movement of the water may show no relation to the land surface whatever. Rock structures and heterogeneity of rocks may cause ground water to move in unanticipated directions.

The increment of water derived from infiltration through the bottom of a pond is superimposed on, and disrupts, the equilibrium conditions of natural replenishment and discharge that normally exist in an aquifer. It is a form of recharge to the aquifer and will form a mound on the water table beneath the pond, as shown diagrammatically in Figure 1*B*. The size of this mound will be determined by the rate at which water is added to the aquifer and its capacity to accept and carry away this additional increment of replenishment. In any event, the increased head and steeper ground-water gradients created by the mound will increase the velocity of movement of the ground water (and concomitantly the distance bacteria or other contaminants will travel) and may cause the water to move in directions counter to the general direction of ground-water flow. A reversal in the direction of ground-water flow is shown by the opposite orientation of the right-hand arrow in Figures 1*A* and 1*B*. If the mound builds up sufficiently, it will merge with the pond bottom, as shown diagrammatically in Figure 1*C*. The situation described previously then obtains in which the zone of aeration is eliminated and waste liquids infiltrate directly to the zone of saturation.

Pumping from an aquifer alters the direction of ground-water movement. Pumped wells develop cones of depression in the water table which induce the flow of water toward these wells from surrounding areas. Thus, as shown diagrammatically in Figure 2, water infiltrating to an aquifer from a waste pond may be attracted to these areas of pumping (lower arrows), although the regional movement of ground water may be the reverse (upper arrows). If, at the pond site, the effects of the pumping are great, the velocity of movement from the pond area to the wells may be high. The area of influence of the pumping may extend thousands of feet from the pumped wells, and if large numbers of wells are being pumped simultaneously, such as in many irrigated and industrial areas, appreciable hydrologic effects may extend over hundreds of square miles. In one Great Plains study, contamination of well water by a waste pond in a direction counter to the regional ground-water gradients was attributed to ground water follow-

lowing "the course of an old river bed." The article stated, however, that irrigation-well pumping affected the water level in the waste pond. Therein lies another possible and equally plausible explanation. In fact, movement of the ground water in the unanticipated direction may have resulted from both the presence of permeable channel deposits, along which movement was favored, and alteration of ground-water gradients by pumping for irrigation.

Conclusion

An effort has been made to point up the value of a sound understanding of local geology and hydrology as a means of minimizing the health hazards of waste-stabilization ponds. In general, the comments apply to all similar sources of pollution. Modern quantitative hydrology and three-dimensional delineation of geology permit reasonably accurate determinations of the quantity of water in the ground, its sources of replenishment, directions of flow, rates of flow, and localities of its discharge.

With this understanding, handicaps imposed by the present limited knowledge of bacterial and wastewater transport in specific ground-water environments can be offset to some extent. In addition to indicating the pollution hazard, the information so acquired will aid substantially in the selection of the pond site and the design of the pond.

Acknowledgment

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ENGINEERING ASPECTS OF FINANCING SEWAGE AUTHORITY PROJECTS *

By Samuel I. Zack

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A sewage project may be considered feasible if it provides for the present as well as for the coming generation and is within the capacity of the present generation to pledge payment for it or to pay for it. However, public need and desire have to be combined with foresight and progressiveness of the governing officials, and the talents of engineers, lawyers, financial advisors, and builders, and particularly with the willingness of the lenders of funds to accept "a pledge to pay" for such a project to become an accomplished fact.

The part of the engineer in preliminary and final design, plan preparation, consultation, and inspection during construction is well known. The engineer's part in financing and reliance on him with respect to the engineering soundness, practicality, and economics of a sewage project by the lenders of funds whether individuals, banks, insurance companies, or other investors is probably less well known.

Because of the magnitude and lasting usefulness of well-planned sewage works, long term financing not only is proper but a necessity to extend the sharing of the burden of costs to future beneficiaries.

Authority and Revenue Bond Financing

Aggressive programs by state health authorities to eliminate old and prevent new pollution, complexities caused by rapid expansion of building developments into suburban areas, existence of municipal and political boundaries and subdivisions, constitutional debt limitations, legalities, and current lack of public support for tax-based financing has brought about a type of financing requiring the issuance of authority or other revenue type of bonds which are dependent on revenues from present and future users of the sewerage works.

Successful experience and exemption from federal income taxes have made bonds of this type attractive to investors. Thus, in Pennsylvania most of the sewerage systems and sewage treatment works since 1945 have been and are being built and operated through authority revenue bond financing.

Pennsylvania sewer authorities (1) may, without referendum, sell bonds up to 40 years' maturity to pay for financing and construction and impose sewer rentals to cover debt service and operating and maintenance expenses. Where new sewers are built, supplementary funds may be obtained from tap fees and from front-foot assessments. To make authority bonds eligible for trust funds, revenues have to provide coverage of 20 per cent over and above average annual debt service. Additional coverages of 5 to 20 per cent are often provided to enhance the security of the bonds. Surplus funds accumulated as the result of coverages become available for extraordinary maintenance, capital addi-

* Presented at the 32nd Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Dallas, Tex.; Oct. 12–15, 1959.

tions, and to redeem bonds prior to maturity.

Ohio has recently enacted legislation to enable revenue bond financing of sewage works. Similar type of financing also is possible in Florida and a number of other states. Coverages of 50 per cent on average debt service or 100 per cent on interest are required in Ohio. In Florida coverages on sewer bonds may be provided from water, gas, utility, and other taxes.

Municipalities in Pennsylvania may also finance sewage works by means of general obligation referendum bonds up to 30 years' maturity, supported by tax funds or sewer rentals, or by non-referendum non-debt revenue bonds supported solely by sewer rentals. This type of financing has not been used to any extent.

Sewage projects may be financed, constructed, and operated by an authority or they may be constructed by an authority and leased back to the municipality for operation. Under the lease back, the municipality does not pledge its taxing power, but it pledges to collect sufficient revenue annually from sewer rentals or from other sources for operation, maintenance, and reserves, and to pay to the authority a predetermined annual lease rental comprising debt service and coverage. The purchaser of authority revenue bonds is secured by an indenture between the authority and a trustee, and the authority is in turn secured by a lease agreement between the authority and the municipality.

Feasibility

Feasibility to provide sewers and sewage disposal for municipalities, built-up developments, or areas which are being built up or likely to be built up is not always obvious. An engineering feasibility study and report as a first step provides preliminary information pertaining to (*a*) the practicality and feasible scope of the project, (*b*) estimates of construction costs, (*c*) front-foot assessments, (*d*) tap-on charges, (*e*) amount of bond issue, (*f*) annual revenue needed for debt service and operation (with and without government funds and state subsidies), and (*g*) estimates of the amount of assessments and tap-on charges and annual sewer rentals which will have to be charged to properties and users served.

The investment banker or financial advisor utilizes the engineer's feasibility report to appraise the project, estimate interest costs and debt service, and to determine other factors essential to sound financing. Local and bond counsel use the report to determine engineering aspects which have a bearing on legalities. Thus, the municipal officials by consideration of the report and consultation with the engineer, financial advisor, and local and bond counsel can avoid undue expense for final engineering work on a project which may not be feasible.

There is actually no accurate measure of feasibility. Not too many years ago an authority project was not considered feasible if sewer rentals were more than $24 per year; then this non-feasible sewer rental figure became $30; then $50. In recent years sewer rentals of as much as $60 to $80 per dwelling unit per year and more, plus tap-on charges of $50 to $150, and sewer assessments of $5.00 to $10.00 per front-foot are not uncommon in authority financing. Because of the problems and detail involved in the organization and collection, front-foot assessments have to be more than nominal to be justified.

To make a new sewer project feasible for suburban areas, it is often necessary to limit future capacity of trunk lines and interceptors to 2 to 3 times present need and to defer sewer construction in sparsely built-up and remote areas. Bond schedules may provide for lease rental payments to

TABLE I.—Construction Contracts and Bond Financing for Sewerage System and Treatment Plant

Authority	Design Equivalent Population	Construction Contracts ($)	Bonds Issued—40-Yr Maturity				Initial Users Equivalent Dwelling Units*	Tap-On Charges ($)	Estimated Average Sewer Rental Dwelling Unit per year ($)
			Date	Total Amount ($)	Discount (per cent)	Net Interest Cost (per cent)			
Mechanicsburg	10,000	1,083,198.60	6-1-49	1,040,000	2.5	3.419	3,000	30.00	30.50
			6-1-50	250,000	3.5	3.263			
Lemoyne	9,000	838,000.00	5-1-49	880,000	0	3.464	1,800	30.00	31.50
			5-1-50	135,000	0	3.250			
Middleburg	1,700	365,906.50	4-1-51	475,000	0	2.789	600	75.00	50.00
Shippensburg	11,700	1,015,841.74	4-1-52	1,300,000	1.0	2.791	2,600	35.00	37.50
			4-1-59	60,000	2.0	4.572			
Catasauqua	16,600	1,394,588.00	4-1-55	1,850,000†	3.0	3.330	3,000	50.00	41.80
Hickory Township	31,500	1,504,612.00	2-1-56	2,090,000†	3.0	4.05	2,400	50.00	50.40
Lower Allen Township	36,000	3,359,633.35	9-15-57	4,550,000	3.2	5.41	5,300	90.00	68.00
Hopewell Township	32,400	1,281,788.40	5-1-58	1,960,000†‡	3.8	5.28	2,700	75.00	56.00
East Pennsboro Township	13,800	1,589,891.65	12-1-58	2,400,000	3.0	5.269	2,700	150.00	78.00

* Used for establishing sewer rentals.
† Front-foot assessments: Catasauqua, $4.00; Hickory Township, $3.50; and Hopewell Township, $5.50.
‡ P. L. 660 grant, additional $205,200.

TABLE II.—Construction Contracts and Bond Financing for Intercepting Sewers and Treatment Plant

Authority	Design Equivalent Population	Construction Contracts ($)	Bonds Issued					Initial Users Equivalent Dwelling Units*	Estimated Average Sewer Rental Dwelling Unit per year ($)
			Date	Years To Maturity	Total Amount ($)	Discount (per cent)	Net Interest Cost (per cent)		
Bloomsburg	15,000	1,043,321.00	4-1-51	30	1,250,000	1.0	2.554	5,600	24.00†
Gettysburg	8,500	415,000.00	10-1-51	40	475,000	0.1817‡	2.618	2,000	17.10
Danville	10,500	410,000.00	2-1-52	27	475,000	0.0786‡	2.016	2,000	17.00
Catawissa	2,000	113,000.00	5-15-52	29	150,000	0	2.731	800	23.50
Baden	20,000	615,230.75	2-1-58	40	930,000	5.5	5.29	2,600	44.30
Monaca	12,600	662,430.85	11-1-57	30	950,000	4.0	5.29	3,200	37.00
Coraopolis	21,000	1,287,516.00	8-1-58	30	1,425,000§	3.0	4.06	4,300	36.00
Harrisburg	200,000	5,596,006.00	4-1-58	25	7,150,000§	1.96	3.012	88,000	10.75
McKeesport	105,500	5,673,471.00	4-1-59	40	7,750,000§	2.41	4.003	34,000	24.80
Christiana	1,500	143,600.00	7-1-58	30	130,000§	3	4.067	360	42.60
White Haven	1,800	221,700.00	2-1-58	40	227,000§	4	5.60	600	36.00
New Holland	6,200	242,880.30	4-1-59	26	310,000	2	3.8716	1,700	30.00

* Used for establishing sewer rentals.
† Includes garbage incinerator.
‡ Premium.
§ P. L. 660 grant additional: Coraopolis, Harrisburg, and McKeesport, each $250,000; Christiana, $52,050; White Haven, $59,175.

be graduated from a minimum comprised of interest and coverage in the initial year to a maximum by about the seventh year, comprised of interest, average debt service, and coverage to retire the bond issue during the remaining period. Sewer rentals can thus be patterned to estimated revenue from future users, where rapid growth or building development is in progress, rather than to the initial users alone.

Engineering Essential to Sale of Bonds

As a next step, if the project is found to be feasible, the engineer prepares construction plans and specifications, the job is advertised, and firm bids are received.

At this point, bonds have to be sold to provide funds for construction. A final engineering report is prepared setting up the estimated amount of bond issue and estimates of present and prospective users of the system, estimates of revenue and fixed and operating expenses, a schedule of sewer rental rates to be charged various types of users, and regulations pertaining to discharge of sewage and industrial wastes to the sewer system.

In the case of a new sewerage system, the amount of assessment per front-foot and tap-on charges are developed and receipts from assessments and tap-on charges are estimated. Where joint use of sewerage works is involved or where service is to be rendered by contract to adjoining municipalities, authorities, or industries, the charges and revenues are established or estimated. This engineering report provides the investment banker

FIGURE 1.—Primary treatment plant at Harrisburg Sewerage Authority, including sludge digestion, dewatering, heat drying, and incineration.

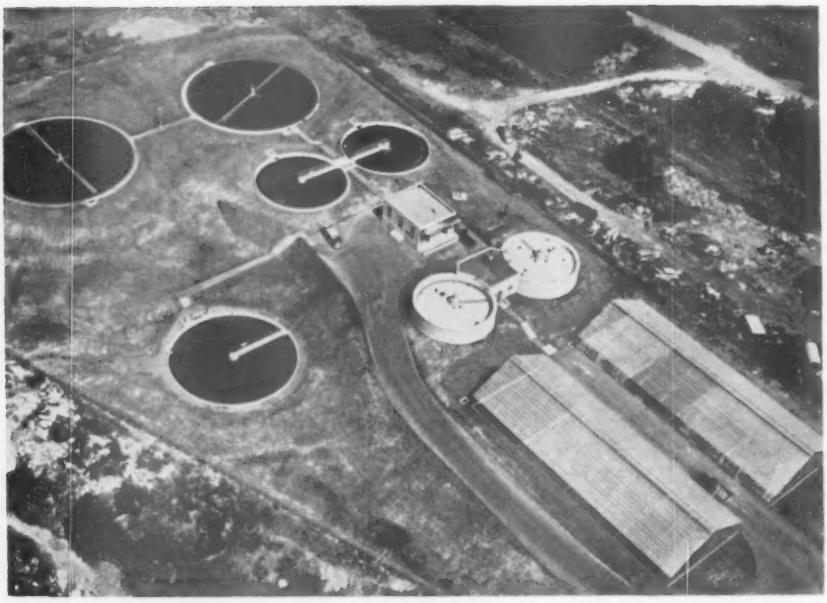

FIGURE 2.—High-rate recirculation trickling filter plant at Catasauqua Borough Authority. Plant uses floating-cover digesters and glass-covered sludge drying beds.

and local and bond counsel with the basis for enacting ordinances and preparation of prospectuses, indentures, and lease agreements. The larger bond issues are usually sold by competitive bidding at public sale and the smaller ones by negotiation with investment bankers.

Bond Issue and Revenue Factors

Details for authority bond financing in 9 Pennsylvania municipalities where sewage systems and treatment plants were financed and constructed are shown in Table I. Table II includes details for 12 Pennsylvania municipalities which financed and constructed intercepting sewers and treatment plants. Photographs of 9 of the treatment plants discussed in Tables I and II are shown as Figures 1 through 9.

Revenue from sewer assessments of $4.00 per front foot at Catasauqua, $3.50 at Hickory Township, and $5.50 at Hopewell Township was set up to retire early maturity bonds in 5 to 7 years, within the framework of the over-all respective authority bond issues. Short maturity bonds had coupon rates up to one per cent less than the long maturities. Sewer rentals were established as the source of revenue in all of the 21 projects. Tap-on charges ranging from about $30 to $150 per connection were established to provide initial revenue and reserves for operation and debt service prior to the time all properties were connected to the sewer system.

In addition to the funds required for the construction contracts, authority bonds included amounts to cover (*a*) engineering costs, (*b*) repayment of federal loans, (*c*) advances by the municipality for prior engineering work or other expenses, (*d*) real estate and rights-of-way, (*e*) local and bond counsel, (*f*) printing bonds and indenture, (*g*) trustee's initial fees, (*h*) authority administrative and working capital, (*i*) initial debt service reserves, (*j*) interest during construc-

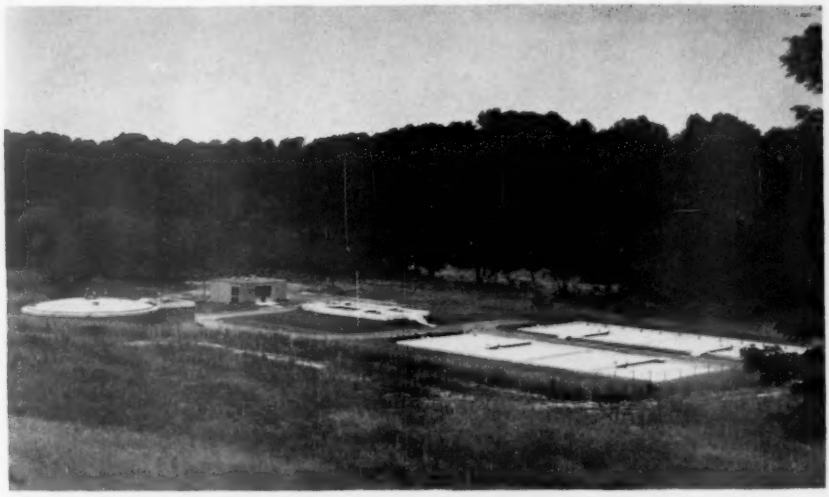

FIGURE 3.—Primary treatment plant at Lower Allen Township Authority. Sludge is dried in open beds.

tion, and (*k*) contingencies. Items making up bond issues for some typical authority sewage projects are shown in Table III.

Some of the other bond issues (Tables I and II) included special items as follows: (*a*) Hopewell Township included $65,000 for subsequent lateral sewer extensions and $33,000 as reimbursement for certain existing sewers; (*b*) East Pennsboro's bond issue included refunding of outstanding bonds in the amount of $58,000 of a prior issue for a small treatment plant and $55,000 to purchase the property of a private sewer company

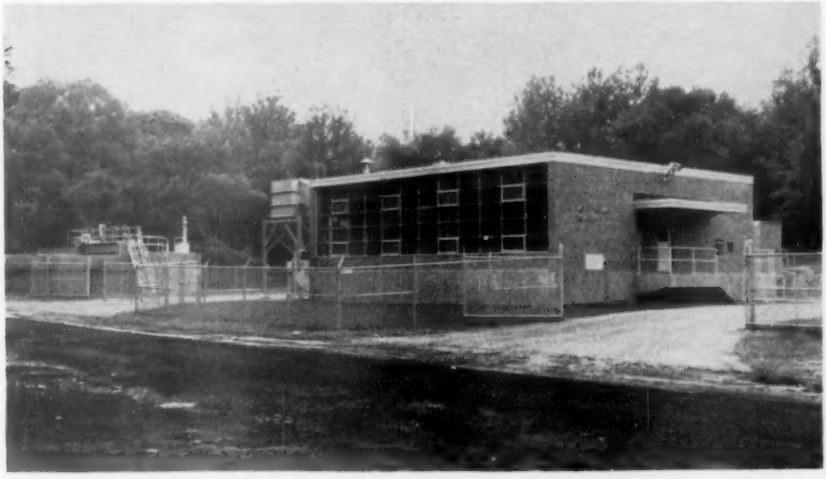

FIGURE 4.—Primary plant at the Municipal Authority of the Borough of Baden. Settling tanks are two-storied. Sludge is vacuum-filtered.

FIGURE 5.—Primary treatment plant at the Monaca Borough Municipal Authority. Digester, settling tanks, and vacuum filter are completely covered.

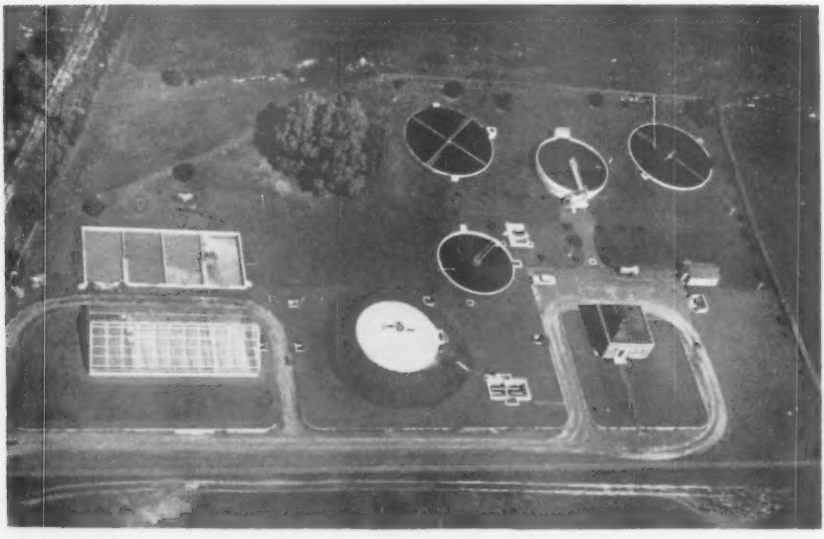

FIGURE 6.—Two-stage, high-rate recirculation trickling filter plant at the Municipal Authority of the Borough of Mechanicsburg.

FIGURE 7.—Single-stage, high-rate recirculation trickling filter plant at the Shippensburg Borough Authority.

and for demolition of an existing deteriorated plant; (*c*) Baden's bonds included $7,500 for purchase of Borough sewers.

Public Law 660 grants were deducted from the project costs in arriving at the amount of bonds to be issued at Hopewell, Coraopolis, Harris-

FIGURE 8.—Single-stage, high-rate recirculation trickling filter plant at the Christiana Borough Authority. Plant uses two-storied settling tanks and open sludge drying beds.

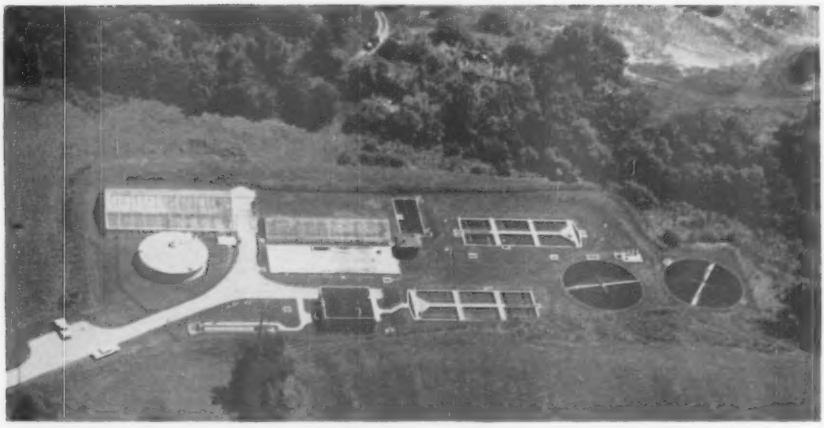

FIGURE 9.—Two-stage, high-rate recirculation trickling filter plant at Gettysburg Municipal Authority.

burg, McKeesport, Christiana, and White Haven. Christiana contributed $5,000 and New Holland $8,000 to the authority, and these amounts were also deducted from the project costs in establishing the amount of bond issue.

Bond indentures provided for authority operation at Bloomsburg,

TABLE III.—Items in Bond Issues of Typical Authority Sewage Projects (Reported in Dollars)

Project	Hickory Township	Lower Allen Township	Coraopolis	Harrisburg	Christiana
	Sewer System and Treatment Plant	Sewer System and Treatment Plant	Interceptors, Pumping Stations, and Treatment Plant	Pumping Stations, Force Main, and Treatment Plant	Pumping Station and Treatment Plant
Construction contracts	1,504,612	3,359,633	1,287,516	5,596,006	143,592
Engineering	155,000	290,000	122,000	492,000[a]	12,000
Real estate and rights-of-way	15,000	35,000	76,800[b]	133,137	—
Legal (local and bond counsel)	21,000	17,500	16,750	55,000[c]	—
Trustee's fees and printing	5,000	5,000	5,000	—	1,125
Interest during construction	116,997	466,375	26,062	429,000	2,465
Bond discount	62,700	136,500	42,750	143,000	3,900
Working capital	6,000	5,000	7,000	20,000	500
Debt service reserve	98,088	—	—	—	5,000
Contingencies	105,603	234,992	91,122	531,857	13,468
Project cost	2,090,000	4,550,000	1,675,000	7,400,000	187,050
Bond issue	2,090,000	4,550,000	1,425,000[d]	7,150,000[d]	137,000[e]

[a] Includes reimbursement to city and Federal Government for prior engineering costs.
[b] Real estate, rights-of-way, and other prior expenses reimbursed to Borough.
[c] Includes financial advisor's fees and printing of bond, indenture, etc.
[d] Federal grant, $250,000.
[e] Federal grant, $52,050—contribution by Borough, $5,000.

TABLE IV.—Annual Revenue and Expenses in Dollars for Initial Years at Shippensburg, Pa.

Year	Revenue					Expenses			Annual Surplus or (Deficiency)	Cumulative Surplus
	Sewer Rentals	Connection Charges*	State Subsidy	Miscellaneous	Total	Operation and Administration	Lease Rental and Loan Repayment	Total		
1954	18,858	41,690	—	—	60,548	1,400	39,300	40,700	19,848	19,848
1955	57,000	19,000	—	—	76,000	14,413	58,555	72,968	3,032	22,880
1956	80,522	4,685	13,963	201	99,371	19,987	90,438	110,425	(11,054)	11,826
1957	85,076	1,070	4,848	214	91,208	18,504	78,000	96,504	(5,296)	6,530
1958	86,442	945	—	3,438	90,825	20,538	75,300	95,838	(5,013)	1,517
1959†	88,500	500	5,240	4,500	98,740	17,800	72,300	90,100	8,640	10,157

* Connection charges started in March 1954.
† Budgeted.

Gettysburg, and McKeesport. In all other cases the respective authorities leased the project back to the municipalities for operation.

Catasauqua, Lower Allen, Hopewell, East Pennsboro, Danville, Baden, Harrisburg, and McKeesport financing included revenue for sewer service under contracts with adjoining authorities or municipalities. The City of McKeesport contracted with the authority for sewer service in lieu of a lease-back to avoid responsibility for possible delinquencies in payments by the other municipalities served.

After sale of bonds the investment banker or advisor determines the financing costs and develops a bond schedule showing the requirements for debt service during the life of the bond issue. Items based on estimates in the previously prepared engineering report on financing are adjusted by the engineer for pertinent factors of the actual bond sale which are at variance with estimates. Prior to bond closing an engineer's certificate or statement is required setting forth his estimate for completing construction of the project, and certification that the established sewer rentals and other charges are estimated to develop sufficient revenue annually for debt service and operation.

It may take from two to four years for all the users to be connected to the sewer system, although recently in some instances connections have been made at a faster rate. Initial operating and maintenance costs and the initial lease rentals are paid out of tap-on charges and initial sewer rentals. Tap-on of properties to the newly constructed sewer system at Shippensburg started March 1954. The actual annual revenue and expenses for 1954 through 1958 are shown in Table IV.

The assessable footage, amount of assessment to be made, and the assessments likely to be collected has to be estimated and certified by the engineer. During recent years experience in collection of front-foot assessments have been very good.

Sewer tap on was started in Catasauqua September 6, 1956. The revenue and expenses at Catasauqua during the initial years 1956–1958 are shown in Table V.

Proceeds of the bond issue are deposited with a trustee, and payments to contractors are released by requisitions from the authority certified by the engineer. The engineer also furnishes general and direct field inspection of construction work and certifies completion and final payment. Proceeds of the bond issue may be reinvested in certain government securi-

ties pending need to pay contractors and to meet other obligations, and interest earned is deposited in the construction fund. No material extensions, modifications, or alterations in plans and specifications can be made without certification by the engineer, and such certificate usually states that in his opinion the security of the bonds will not be adversely affected and that costs will not be increased in excess of the amount available in the construction fund.

Types of Sewer Rentals

The type of sewer rentals charged to residential users varies for different municipalities or authorities. Where water is metered the rentals are usually based on either a percentage of the water bill or on a rate schedule applicable to sewage charges more or less parallel with the schedule of water rates. In some cases, sewer rentals are based on a flat rate or on a fixture rate.

Water supplied to large commercial and industrial establishments is usually metered; therefore, sewer rentals for such users are practically always based on metered water use, with credit allowed for water not discharged to sewers. Sewer rental rates usually include a surcharge for strength of wastes. Regulations prevent the discharge of detrimental wastes and may compel pretreatment or flow equalization before discharge.

Most water rate schedules are graduated to provide a lower rate for water used by the large consumer and many sewer rental rates are established to parallel the water rates. Under such a schedule sewer rentals charged to a large user may be less than the actual cost of handling and treating his sewage. To avoid placing an undue burden on the residential user, only the upper brackets of the water rate schedule may be made applicable to sewer rental rates, thus limiting preferential rates to large users as far as sewage charges are concerned.

In the case of Harrisburg a uniform sewer rental rate of 26¢/1,000 gal and at McKeesport, 52¢/100 cu ft of water use was established for all users —small and large, residential, commercial and industrial.

Insurance Coverage

Under an authority operated sewage project, the authority and under a lease-back both the authority and the borough are required to provide insurance for treatment structures and mechanical equipment against such risks as are normal to treatment plant operations including fire, theft, vandalism, malicious mischief, and all perils normal to extended coverage endorsements.

Actual and insurable values of

TABLE V.—Annual Revenue and Expenses in Dollars for Initial Years at Catasauqua, Pa.

Year	Revenue							Expenses			Annual Surplus†	Cumulative Surplus†
	Front-Foot Assessment	Sewer Rentals	Connection Charges*	State Subsidy	North Catasauqua	Miscellaneous	Total†	Operation and Administration	Lease Rental	Total		
1956	None	7,000	24,987	None	1,802	None	33,789	2,584	None	2,584	31,205	31,205
1957	285,200	42,000	47,600	8,930	10,816	281	109,627	17,240	56,250	73,490	36,137	67,342
1958	4,700	91,067	3,525	10,039	15,913	1,179	121,723	23,383	74,250	97,633	24,090	91,432

* Connection charges started in September 1956.
† Excluding front-foot assessment revenue.

treatment plant structures now covered by insurance for various municipalities are shown in Table VI.

Foundations below the lower floor are not insurable and risks pertaining to clarifier, filter, and drying bed structures are negligible and usually do not justify the payment of insurance premiums. However, in some cases all structures are covered and the weighted risk is reflected in premiums charged. Glass superstructures, however, are also insured against damage of wind and hail.

Treatment plant operating personnel are normally protected by Workmen's Compensation. A municipality or authority is protected from claims of injury or damage arising out of sewer system and treatment plant operations by the public liability and property damage insurance. Insurance held on treatment plant structures and mechanical equipment is mostly of non-assessable 80- or 90-per cent co-insurance type and written to the benefit of the authority, borough, and trustee under the indenture. All officials of the borough and authority as well as borough employees handling sewer system funds are covered by fidelity bonds.

The engineer has to establish the current value and insurable values of the property and the proper amount of insurance to be carried by the authority or municipality, or both.

TABLE VI.—Construction Cost and Insurable Values in Dollars of Treatment Plants

City	Construction Cost	Present Insurable Values
Catasauqua	569,100	221,000
Bloomsburg	904,500	724,400
Danville	321,900	199,100
Mechanicsburg	309,100	115,300
Lemoyne	153,900	113,200
Shippensburg	339,600	217,400

Additional Functions of Engineer

Stipulations under indentures and leases of authority bond issues require the employment of a consulting engineer as long as bonds are outstanding. In conformity therewith the engineer is usually engaged under a continuing contract to furnish the services required annually.

After the project is placed in operation the engineer has to certify annually that in his opinion the schedule of rates and charges in effect (*a*) will yield sufficient revenue for the expenses of operation, maintenance, and repairs and for required debt service and reserves; (*b*) that the project is or is not in a proper state of maintenance and repair; (*c*) will cover repairs, renewals, or replacements needed for suitable and efficient operation of the project and the estimated cost thereof; and (*d*) that adequate amounts of fire and casualty insurance are carried by the authority or municipality.

These requirements actually necessitate preparation of an annual budget by the engineer on operation of the project, or at least the approval by the engineer of a budget prepared by the governing body. It also necessitates periodic inspection of the sewage works to (*a*) assure efficient and economical operation, (*b*) determine the amount of maintenance, repairs, and improvements, and (*c*) furnish instructions to operators and preparation and submission of reports to the governing body covering findings and recommendations.

In the event of loss or damage to the project by fire or otherwise the engineer has to certify the repairs, renewals, or replacements that have to be made and the payment for them. Sale or lease of any property of the project must be certified by the engineer. In some cases, the engineer is required to make general inspection of the operating records and policies of the authority and make recommendations as to operating records, renewals, replacements, alterations, ad-

TABLE VII.—Actual Revenue and Expenses in Dollars for One Year

Item	Bloomsburg[a] (3-31-58 to 4-1-59)	Catasauqua (1-1-58 to 12-31-58)	Danville (1-1-58 to 12-31-58)	East Pennsboro (6-1-57 to 5-31-58)	Lemoyne (5-1-58 to 4-30-59)	Mechanicsburg (6-1-58 to 5-31-59)	Mercersburg (3-15-58 to 3-14-59)	Shippensburg (4-1-58 to 3-31-59)
Revenue (at start of year)	—	67,200	208	964	11,791	33,664	11,602	6,533
Sewer revenue fund balance	128,606	91,067	52,636	4,007	70,481	109,831	38,495	86,442
Sewer rental receipts	12,425	848	—	—	—	—	—	—
Accounts receivable	10,298	10,039	—[b]	642	2,741	—[b]	2,978	(Not Received)
State subsidy	265	3,525	—	350	—	330	—	945
Connection fees	3,694	331	—	35	—	—	—	230
Penalties and interest	1,345[c]	15,913[d]	60	1,494[e]	408	50	250	3,208[f]
Other income and miscellaneous	156,633	188,923	52,904	7,492	85,421	143,875	53,325	97,358
Total revenue								
Expenses								
Sewer system	—	1,205	—	—	—	—	—	2,400
Salaries and wages	5,288	—	—	—	1,315	4,546	416	2,014
Maintenance, repairs, and supplies	5,288	1,205	—	—	1,315	4,546	416	4,414
Sub-total								
Sewage treatment and pumping stations	38,508	6,672	6,415	1,092	3,802	7,926	3,484	3,900
Salaries and wages	5,584	3,275	1,735	744	781	2,304	492	1,554
Supplies	3,454	3,584	2,425	329	528	2,671	892	2,736
Power	1,499	1,077	948	—	1,054	2,455[g]	749	247
Fuel oil and gasoline	—	355	—	—	—	235	95	86
Telephone	6,646	865	540	171	2,650	1,169	677	831
Maintenance and repairs	3,393	1,153	758	97	—	632	261	985
Miscellaneous	59,084	16,981	12,821	2,433	8,815	17,392	6,650	10,339
Sub-total								
Administration	4,879	2,993[h]	1,200	—	1,500	5,987	1,827	2,400
Salaries and wages	2,091	—	1,000	119	1,540	256	135	213
Supplies and billing costs	1,873	—	300	—	500	758	—	390
Legal	1,342	—	10	10	250	215	132	400
Auditing	2,453	366	841	24	253	850	341	666
Insurance	2,275	1,600	1,800	400	350	1,200	550	1,400
Engineering	1,489	238	144	990[i]	495	398	134	3,316[f]
Miscellaneous	16,402	5,197	5,295	1,543	4,888	9,664	3,119	8,785
Sub-total								
Fixed expenses—lease rental	59,525[h]	74,250	34,500	3,000	54,919	68,000	35,405[j]	72,300
Total expenses	140,299	97,633	52,616	6,976	69,937	99,602	45,590	95,838
Surplus funds	16,334	91,290	288	516	15,484	44,273	7,735	1,520

[a] Includes refuse incinerator.
[b] Paid to authority not included in revenue of municipality.
[c] Rent, incinerator service, and sludge sales.
[d] For sewer service under contract with North Catasauqua.
[e] For sewer service under contract with Camp Hill.
[f] Includes $3,000 from General Fund.
[g] Includes light and water.
[h] Includes billing costs.
[i] Rentals for service to Camp Hill.
[j] $3,316 transfer to General Fund.
[k] Debt service under authority operation.
[l] Includes repayment of $5,605 bank loan.

ditions, improvements, or extensions or changes in operating policy.

Subject to certification by the engineer, reserve funds established for maintenance and repairs and as redemption and improvement funds may be used for renewals, replacements, repairs, additions, and extensions or improvements necessary for proper operation, maintenance, or repair of the project when the expense of such work is outside the scope of the ordinary maintenance and operation.

If reserve funds for maintenance or improvements are to be used for redeeming bonds, certificate from the engineer is required to the effect that in his opinion money in such funds will not be required for maintenance, repairs, or extensions.

In the event additional bonds have to be issued, the engineer has to certify that the bonds are being issued and are necessary for the cost of completing the project or for extraordinary repairs, renewals, replacements, extensions, or improvements; that such construction is required for proper and effective operation of the plant; that the funds being provided are estimated to be sufficient; and that the annual revenues of the project estimated under existing schedule of sewer rentals or under a supplementary rental schedule will be sufficient to cover the cost of operation, fixed charges, and reserves. No capital additions are permitted without certification of the engineer that such additions are useful or desirable and that the sewer rentals in effect or to be put into effect will be sufficient for operation, fixed charges, and reserves.

The foregoing outlines the principal duties and responsibilities of the engineer under the trust indenture securing bonds issued by authorities, and lease between the authority and the municipality, although such duties and responsibilities may vary to some extent from one indenture and lease to another.

Revenue and Expenses for One Year

Each year budgets are prepared for the agency operating the authority sewage project. Actual annual revenue and expenses have been reasonably close to budgeted amounts. Actual revenue and expenses for the most recent year for eight authority projects are presented in Table VII. Actual experience with authority projects' operation range from about three years by Catasauqua to about nine years by Mechanicsburg and Lemoyne. Revenues have been sufficient to meet expenses annually for all of the authority projects outlined.

Conclusions

It is evident that financing of sewage projects by authority bonds and annual sewer rental revenues and with connection charges, with or without front-foot assessments in the case of sewer systems, provides practical means for construction and operation of such projects, when a municipality cannot or is not willing to finance such project through the sale of general obligation bonds and to service such bonds through tax revenues.

Interest rates for authority bonds have been somewhat higher than for general obligation bonds. Authority bond interest rates have not been excessive indicating that bond purchasers of authority bonds do not consider investment in authority bonds for sewage projects particularly risky. There has always been and there still is an active demand for these bonds.

The engineer has a definite responsibility in authority type of financing: (*a*) to establish feasibility of the project by preliminary investigation, (*b*) to prepare construction plans and specifications, detailed estimates of construction cost, amount of bond issue, annual receipts, and revenues to meet expenses of operation and maintenance and fixed charges, and (*c*) to provide inspection during construc-

tion. From the time the bonds are sold until they are retired, the engineer in acting for the authority or municipality is actually required to perform professional duties under the indenture and lease in the interests of the bond purchaser which are essential to the security of the bonds.

In some instances, subsequent to completion of a feasibility report, public opposition has delayed but not prevented the project from finally going ahead. However, once bids have been received and the project financed for construction, public opposition has been nil toward making connections to the new sewer systems, or to connection charges, front-foot assessments, or sewer rentals.

Experience with sewer rental collections has been satisfactory. The revenues collected have been sufficient to meet annual expense requirements and to set up required reserves. In many cases, surplus funds have been used for sewer extensions to newly built-up areas, to make additions and improvements to the plant, or to retire bonds prior to maturity. Many of the bonds issued earlier at lower interest rates have been advantageously purchased by authorities at or below par. The cushion provided by the reserves and revenue over requirements makes it possible to reduce rental rates.

The annual subsidy in Pennsylvania has greatly enhanced the security of bonds and has made projects possible which otherwise would have been marginal or unfeasible. The federal grants have further stimulated construction and have aided financing of sewage projects. Both the state subsidies and the federal grants are of greater material benefit to small municipalities where they reflect greater reduction in annual sewer rental costs per dwelling unit.

Reference

1. Public Law 382, Commonwealth of Pennsylvania (May 2, 1945).

CORRECTION

In the paper, "High-Rate Digester Performance at Jamaica," by Norman Nash and A. H. Chasick (THIS JOURNAL, **32**, 5, 526; May 1960), the second sentence of the first paragraph of page 527 should read: "Wishing to apply this work . . ." On page 531 under the heading *Solids Concentration*, the second sentence should start: "Digesters 9 and 10 produced . . ." In the headings of Table II on page 532, "Transfer Sludge" should be substituted for "Thickened Raw Sludge," and "Digested Sludge" should be substituted for "H-R Digested Sludge." The last sentence in the second paragraph on page 537 should read ". . . scum accumulation, if it occurs, can be observed."

Industrial Wastes

A PROCEDURE FOR DETERMINATION OF THE BIOLOGICAL TREATABILITY OF INDUSTRIAL WASTES

By James M. Symons, Ross E. McKinney, and Herbert H. Hassis *

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The backbone of good research is the use of well-established, standardized procedures for the analytical determinations which yield most of the data. The use of standard procedures allows the ready comparison of data collected by different researchers in different laboratories because it is known that these various pieces of data were taken in the same way. The absence of standard methods would lead to chaos in the field of research. To prevent this difficulty in the field of sanitary engineering, a series of standard analytical tests has been outlined in "Standard Methods" (1). All researchers in sanitary engineering are urged to follow these outlines.

This concept of standardization could be applied to other procedures in sanitary engineering research as well as to the analytical techniques. One of these procedures is the determination of aerobic biological treatability of industrial wastes. For this determination, almost all researchers have a different method of operating their pilot plants. The analytical determinations made on the pilot plants are made following "Standard Methods" (1), but these data are difficult for others to interpret because of the varying conditions under which the pilot plants themselves are operated.

It is the purpose of this paper to outline a procedure for the determination of aerobic biological treatability of industrial wastes by the use of pilot plants. It is hoped that others might find this procedure reasonable and follow it. This would provide some standardization in this phase of sanitary engineering research.

Literature Review

The literature shows the wide variation of pilot plant procedures. Dougherty *et al.* (2), Coe (3), and Hatfield and Strong (4) used continuously fed pilot plants with varying aeration times, while Logan and Heukelekian (5), Rudolfs and Amberg (6), McKinney and Jeris (7), McKinney *et al.* (8), Kountz (9), and Helmers *et al.* (10) used fill-and-draw pilot plants with aeration times varying from 8 to 23 hr.

Dougherty *et al.* (2) used Na_3PO_4 and $NaNO_3$ for nutrient supplementation while Moggio and Gehm (11) used NaH_2PO_4 and ammonia gas. A 5-day BOD-to-phosphorus ratio of 60 to 1 was maintained by Amberg and Cormack (12) while Sawyer *et al.* (13) used NH_4OH for acid wastes and $(NH_4)_2SO_4$ for alkaline wastes, maintaining a 5-day BOD-to-nitrogen ratio of 20 to 1. KH_2PO_4 was used to keep a 5-day BOD-to-phosphorus ratio of 150 to 1. Logan and Heukelekian (5)

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used NH_4Cl and K_2HPO_4 while Rudolfs and Amberg (6) added NH_4NO_3 and $(NH_4)_2HPO_4$ to hold a 5-day BOD-to-nitrogen ratio of 20 to 1 and 5-day BOD-to-phosphorus ratio of 40 to 1.

Some investigators (3) (12) (14) have acclimated their sludges by building up a sufficient solids concentration on sewage and then slowly increasing the waste concentration while decreasing the quantity of sewage fed. Others (6) (15) have used cultures obtained from operating activated sludge plants. Still others have developed very specific procedures of acclimating activated sludges to various organic substrates. Strong and Hatfield (16) worked with a petrochemical waste high in formaldehyde; Mills and Stack (17) tested many pure organic compounds; and McKinney *et al.* (8) acclimated sludges to various aromatic substrates.

Other operational procedures which vary widely are those of sludge recirculation and suspended solids concentration. Strong and Hatfield (16) and McKinney *et al.* (8) recycled all of the secondary sludge by wasting only supernatant liquor. McKinney and Jeris (7) returned 67 per cent, Kountz (9) 50 per cent, Morgan (18) 35 per cent, and Logan and Heukelekian (5) 25 per cent of the settled secondary sludge. Other researchers have held constant suspended solids levels rather than set any fixed rate of return sludge. Dryden *et al.* (19) varied the mixed liquor suspended solids from 1,050 mg/l to 5,000 mg/l as the 5-day BOD rose from 730 mg/l to 3,600 mg/l. Suspended solids concentrations of 1,000, 2,000, 3,000, and 4,000 mg/l were held for wastes with 5-day BOD's of 2,000, 2,500, and 4,300 mg/l by Rudolfs and Amberg (6). Sawyer *et al.* (13) studied a waste with 565 to 800 mg/l 5-day BOD by using 1,500 mg/l of aeration solids.

As can be seen, the methods of operating activated sludge pilot plants to determine the amenability of industrial wastes to biological treatment are quite variable.

Suggested Procedure

It is important to remember that the procedure outlined below is for the determination of biological treatability only, and not for the establishment of design criteria. Suitable design factors have already been established and can be applied once the extent of biological degradation for a particular industrial waste is determined. The procedure used in the following outline does not exactly match field practice, but this is of no concern since only biological treatability is being determined, not design criteria. The aerobic biological treatability as determined by this procedure is applicable to trickling filter installations as well as activated sludge plants since both are aerobic biological processes.

Raw Waste Analysis

1. Chemical oxygen demand (COD). The COD of the raw waste will give a measure of 90 to 99 per cent of the organics present. Care must be taken always to use silver sulfate as a catalyst to aid in the breakdown of certain organics.

2. Five-day biochemical oxygen demand (BOD). The ratio of the BOD of the raw waste using sewage seed to the COD will give an indication of the extent of degradation which can be expected using unacclimated organisms. A ratio of 0.6 or higher will indicate a waste which can be easily and completely treated. A low ratio, near 0.2, will indicate either the presence of some undegradable organic matter or the necessity for acclimation to get complete removal. A ratio of 0.0 will indicate an industrial waste which is toxic to unacclimated organisms.

3. Nitrogen content—all forms (NH_3–N, NO_2–N, NO_3–N, Org–N). As an essential growth factor for bacteria, ample nitrogen must be present. All

forms of nitrogen are available to the microorganisms, but the organic nitrogen in the raw waste will not become available until the organics are being degraded. Therefore, initially the organic nitrogen cannot be counted on for supplementation. A COD-to-nitrogen ratio of 20 to 1 has been found to provide ample nitrogen. If the total inorganic nitrogen in the raw waste is insufficient, the deficit should be made up with $(NH_4)_2SO_4$. The NH_3–N content of this chemical is 21.2 per cent of its molecular weight. This adds nothing to the system which will interfere with any other tests, except if sulfate release studies are to be made in connection with synthetic detergent work. In that case, $(NH_4)_2HPO_4$ is recommended.

4. pH. The pH of the waste as fed to the pilot plant, diluted if necessary, must be near neutrality if biological activity is to proceed unimpeded. If pH adjustment is necessary, it should be raised with sodium or potassium hydroxide or lowered with sulfuric acid. The use of these chemicals will prevent any precipitation of solids in the raw waste. The introduction of solids into the pilot plant would tend to interfere with the treatability determination.

5. Titration curve. An acid-base titration curve of the waste as fed to the pilot plant, diluted if necessary, will tell if the waste itself contains sufficient buffer capacity to hold the pH between 6.5 and 8.0 during biological metabolism. If insufficient buffer is present, chemicals must be added to provide buffer.

6. Phosphorus content (PO_4–P). Phosphorus is as essential for bacterial growth as nitrogen. Both must be present in ample amounts if biological growth is to proceed unimpeded. If buffer is required for the study, a phosphate buffer system should be used, and enough PO_4–P for bacterial growth will be provided. In this case, the PO_4–P content of the raw waste need not be determined. If the raw waste has ample buffer, care must be taken to provide a COD-to-PO_4–P ratio of 100 to 1. If insufficient PO_4–P is present, K_2HPO_4 should be added. The PO_4–P content of this chemical is 17.8 per cent of its molecular weight.

7. Other trace elements. If tap water is used to dilute the raw waste, sufficient trace elements will be present to allow ample biological growth. If there is to be no dilution, care must be taken that the essential trace elements are present in the waste.

Type of Aeration Unit

Batch-fed, fill-and-draw type of aeration units should be used. This type of unit is recommended over the continuous-feed pilot plant for the following three reasons. One, a batch-fed unit need only be fed once a day, except in unusual cases, and does not require the use of low capacity pumps, which are often expensive and cumbersome, to maintain continuous feeding. Two, continuously fed pilot plants create a problem of sludge settling and sludge return that is often difficult to solve on such a small scale. Batch-fed units with their air supply turned off become perfectly quiescent settling basins in which the sludge settles very well. This positive sludge retention prevents the loss of sludge in the effluent. Three, the high concentration of organic matter at the start of the aeration period in batch-fed units often stimulates necessary adaptive enzymes for metabolism which would not be stimulated under the low concentration conditions created with a continuously fed, completely mixed pilot plant. If toxic compounds are suspected in the industrial waste, however, a continuous-feed pilot plant may be necessary to prevent the high concentration of toxic material which would exist if a batch-fed unit were used.

Units such as shown in Figure 1 are suggested for use as they are compact, lightweight, inexpensive, easy to con-

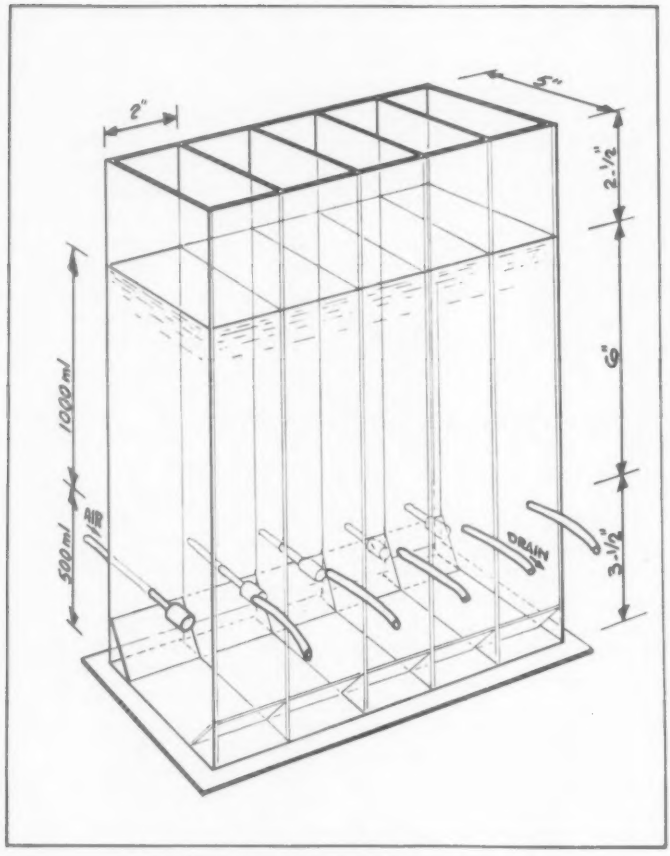

FIGURE 1.—Batch-fed pilot plant.

struct, and easy to operate. They are constructed of 1/8- or 3/16-in. precut plastic and put together with plastic solvent. The porous stone diffusers may be obtained in a tropical fish supply store. Each unit is 12 in. high, 2 in. wide, and 5 in. deep with a liquid depth of 9½ in. and a liquid drawoff 3½ in. from the bottom. Five such units make up a set. A set of five units can be constructed for about $25. The only external connection required is to a 10-psi air line which will deliver at least 2 l/min of air.

The capacity of each unit is 1.5 l. At the end of the aeration period, the air is turned off and the sludge is allowed to settle and 1.0 l of supernatant liquor can be withdrawn. When 1.0 l of new feed is added to the 0.5 l of return sludge, there is a 33 per cent sludge return on a volume basis. All of the sludge is returned, however. If sludge wasting is desired, it may easily be accomplished by withdrawing the desired amount of mixed liquor before the air is turned off. Biological treatability studies are run with 100 per cent return sludge, however, to insure the presence of a high concentration of organisms.

The results of the treatability tests in these units can be applied directly to field installations without any

larger-size pilot plant studies. Since there will exist in the mixed liquor a biological population of about 10^7 to 10^9 bacteria per ml, the bacteria will not know if they are surrounded by 1.5 l, 55 gal, or 1.5 mil gal of liquid. Therefore, their behavior is not affected by the size of the system in which they are growing.

Aeration Period

The aeration time should be 23 hr followed by 1 hr of settling. This time is chosen for convenience, as it allows the researcher to feed the units at the same time every day. The waste may be stabilized before the end of the aeration period, but this does not matter. This long an aeration period has the advantage of giving ample time for hard-to-degrade organic matter to be adapted to by the bacteria and, therefore, may improve the final results.

Feeding Criteria

These systems should be started on a feed containing 1,000 mg/l of COD. Stronger wastes should be diluted to this concentration. If the organics are being completely removed, this concentration will drop to 667 mg/l because of the 1.5-l capacity of the unit. If the waste is not being completely removed, this dilution effect will be lessened, but the concentration immediately after feeding can never exceed 1,000 mg/l COD.

This concentration is maintained at a high level to promote the development of enough sludge with which to work. If a conventional concentration of 300 mg/l of COD were maintained right after feeding, the solids level would remain low. The high rate of oxygen transfer available in this type of pilot plant permits the use of a high concentration of COD.

Three problems must be noted in connection with this feeding criteria. One, if the recommended concentration of 1,000 mg/l of COD causes toxic conditions, the concentration must be reduced. Two, if the waste is not being completely metabolized because of the presence of some resistant organic matter, the feed concentration should be raised until the concentration of COD of the feed minus the concentration of soluble COD in the effluent is 1,000 mg/l. This will prevent the unit from starving. Three, if a weak waste is involved, one with a COD of less than 1,000 mg/l, the pilot plant should be fed often enough, at regular intervals, so that the total COD removed per day in mg is equal to 1,000. This again prevents the unit from starving.

Buffer

Potassium monobasic phosphate, KH_2PO_4, or potassium dibasic phosphate, K_2HPO_4, are excellent buffers, supplying needed phosphorus as well as buffering action. When biological degradation causes the pH to rise, potassium monobasic phosphate should be used to hold the pH down. When biological action tends to lower the pH, potassium dibasic phosphate should be used to buffer the pH up. A 1,000-mg/l buffer solution is often very satisfactory to hold the pH near 7.0.

The type of buffer required can often be anticipated from a knowledge of the contents of the raw waste. Upon degradation, neutralized organic acids tend to raise the pH by cation release. Protein materials will raise the pH at first by ammonia nitrogen release, but will eventually lower it when the ammonia nitrogen is nitrified to nitrate nitrogen. When carbohydrates or aromatics are metabolized, a low pH results. This can be used as a guide as to what type of buffer is necessary.

Acclimation Procedures

The outline scheme shown in Figure 2 is recommended as a logical approach to the problem of acclimating the pilot-plant sludge to the industrial waste being studied. The extent of biological treatability can be determined only

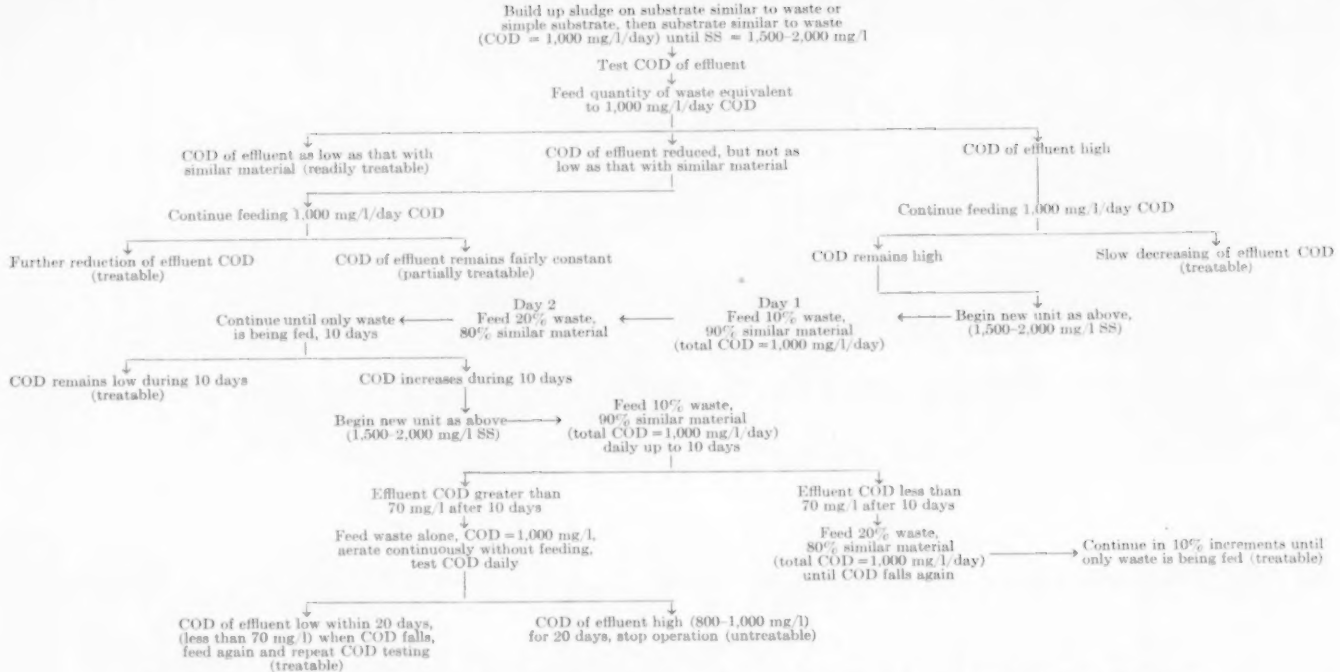
Build up sludge on substrate similar to waste or simple substrate, then substrate similar to waste (COD = 1,000 mg/l/day) until SS = 1,500–2,000 mg/l
Test COD of effluent
Feed quantity of waste equivalent to 1,000 mg/l/day COD
COD of effluent as low as that with similar material (readily treatable)
COD of effluent reduced, but not as low as that with similar material
COD of effluent high
Continue feeding 1,000 mg/l/day COD
Continue feeding 1,000 mg/l/day COD
Further reduction of effluent COD (treatable)
COD of effluent remains fairly constant (partially treatable)
COD remains high
Slow decreasing of effluent COD (treatable)
Day 2
Feed 20% waste, 80% similar material
Day 1
Feed 10% waste, 90% similar material (total COD = 1,000 mg/l/day)
Begin new unit as above, (1,500–2,000 mg/l SS)
Continue until only waste is being fed, 10 days
COD remains low during 10 days (treatable)
COD increases during 10 days
Begin new unit as above (1,500–2,000 mg/l SS)
Feed 10% waste, 90% similar material (total COD = 1,000 mg/l/day) daily up to 10 days
Effluent COD greater than 70 mg/l after 10 days
Effluent COD less than 70 mg/l after 10 days
Feed waste alone, COD = 1,000 mg/l, aerate continuously without feeding, test COD daily
Feed 20% waste, 80% similar material (total COD = 1,000 mg/l/day) until COD falls again
Continue in 10% increments until only waste is being fed (treatable)
COD of effluent low within 20 days, (less than 70 mg/l) when COD falls, feed again and repeat COD testing (treatable)
COD of effluent high (800–1,000 mg/l) for 20 days, stop operation (untreatable)

FIGURE 2.—Outline of acclimation procedures for the determination of biological treatability of industrial wastes.

by the use of a thoroughly acclimated sludge. First, the general nature of the organics in the waste must be determined. This information can often be supplied by the industry, but if they do not know the major components of the waste stream, a check of the raw materials used and products produced will tell something about what the waste will contain. Once the waste has been characterized, an activated sludge should be developed on a substrate which is similar to the main constituent of the industrial waste, but is itself easy to degrade. Examples of these similar substrates are given in Table I. If the industrial waste is a mixture of components, use the appropriate mixture of simple substrates.

The pilot unit may be seeded with sewage, a soil suspension, or sludge from any operating unit in the area. The unit should be aerated until visible floc is formed. This takes about two days. The system should then be settled and refed daily until the mixed liquor suspended solids (MLSS) have reached about 1,500 to 2,000 mg/l. The unit is now ready to receive its first load of industrial waste. In some particularly difficult situations, the material similar to the industrial waste may not be simple enough on which to develop the sludge. For example, if the industrial waste contains alcohols or aldehydes, the sludge might be developed on ethyl alcohol or butyraldehyde, except that in high concentration these are toxic. Therefore, the sludge should be grown to a MLSS level of 1,500 to 2,000 mg/l on sodium acetate and then over a ten-day period add the ethyl alcohol or butyraldehyde in 10-per cent increments, decreasing the sodium acetate feed 10 per cent each day. This slow acclimation will overcome the toxicity of the substrate. When the sludge is thoroughly acclimated to the intermediate substrate, the industrial waste study may begin.

When the MLSS have reached the desired level, the soluble COD at the end of the aeration period is determined to establish a base level of COD for the pilot unit when it is completely degrading a substrate. The unit is then fed the industrial waste, and at the end of the next aeration period, the soluble COD is measured again. If the COD is as low as the base level, the system has already acclimated to the industrial waste; if the COD is partially reduced, some acclimation has taken place; if the COD is high, 600 to 700 mg/l, no initial degradation has been accomplished. The COD of the effluent will fall from the 1,000 mg/l in the feed to 667 to 700 mg/l by dilution.

TABLE I.—Simple Substrates for Developing Activated Sludges

Major Constituent of Industrial Waste	Substrate for Sludge Development
Short chain fatty acids	Sodium acetate
Long chain fatty acids	Castile soap
Proteins	Nutrient broth
Carbohydrates	Glucose or sucrose
Aromatics	Sodium benzoate

Continue feeding the pilot unit and continue testing the soluble COD of the effluent; it will either fall to the base level—final acclimation, remain constant at a value above the base level —partial acclimation, or rise toward 1,000 mg/l—no acclimation. If there is no acclimation by this procedure, start a new unit in the same manner as above, but this time add only 10 per cent of the industrial waste on the first day while feeding 90 per cent of the development substrate. The percentage of industrial waste fed is increased 10 per cent per day and the concentration of the development substrate is decreased 10 per cent per day until after ten days, industrial waste alone is being fed. This allows the organisms to acclimate slowly to the wastes. If the soluble COD does not rise during the ten days, the organisms are acclimated; if it does rise as more industrial waste is added, no acclimation has occurred.

If acclimation does not occur by

this technique, another unit is developed, and when ready, the system is fed 10 per cent of the industrial waste and 90 per cent of the development substrate. This time, however, this ratio is maintained for at least ten daily feedings rather than being changed the following day. If at the end of ten days the COD in solution is less than 70 mg/l (the industrial waste is contributing a COD of 100 mg/l to the feed), the ratio may be changed to 20 per cent industrial waste and 80 per cent development substrate. The first ratio, of course, may be maintained for more than ten days if desired. The 20-per cent : 80-per cent ratio is fed until the COD of the effluent falls again, and when this occurs, the concentration of industrial waste may be increased another 10 per cent. This procedure continues in 10 per cent increments until only industrial waste is being fed and final acclimation has taken place.

If the feeding of 10 per cent industrial waste and 90 per cent development substrate for about 10 days does not promote acclimation, one more approach is available: feed full strength industrial waste, 1,000 mg/l COD, and maintain aeration for several days without refeeding. This gives slowly developing adaptive enzymes time to form under conditions of high food concentration which will tend to stimulate them. Do not refeed until the COD in solution has decreased. Set the aeration period by measuring the soluble COD in solution. Slowly this period will shorten until one day is sufficient for stabilization. If 10 to 20 days pass from the first feeding and no COD reduction has occurred, the waste is untreatable or at best extremely resistant to biological degradation. If toxicity is suspected, the above procedures may be repeated using a maximum industrial waste concentration of 500 mg/l or 250 mg/l as COD. Little sludge will develop if acclimation to the latter concentration occurs.

Control Tests

The following control tests are recommended for the determination of the condition of the pilot plant:

1. Total and volatile mixed liquor suspended solids. A continuing rise in the volatile MLSS in a pilot unit which is being operated with 100 per cent sludge return is a good indication of a well-operating system. The volatile solids are important as the total solids may rise because of the buildup of inorganics in the system.

The MLSS should be determined by the membrane filter method described by Engelbrecht and McKinney (20). This method is preferable over the Gooch-crucible method as it is faster and easier. A membrane filter is placed in an aluminum weighing dish and weighed. A given quantity of mixed liquor, usually 25 ml, is collected with a volumetric pipette, which has had the tip cut off to permit large solids to pass into it, and passed through the membrane. The small pore opening retains all of the solids and is constant from membrane to membrane. After drying at 103°C for 1 to 2 hr, it is reweighed. The pan cools almost immediately after removal from the oven. The dried membrane is placed in a tared crucible, covered to prevent loss of ash, and burned at 600°C for 1 hr. Reweighing after cooling gives the ash content of the sample on the membrane. The membrane itself is ashless.

2. pH. The pH of the mixed liquor should be determined after feeding and at the end of the aeration period. Both pH's are important and both must be in the 6.5-to-8.0 range to promote good bacterial growth. If the pH's are not in the proper range, the buffer must be altered to keep them there. If trouble is suspected, the pH should be checked during the aeration period as it might fall, then rise again to be satisfactory by the end of the

aeration period. This dip must be prevented.

3. Microscopic examination. Examination of a drop of mixed liquor at 100× magnification can tell much as to the general condition of the sludge. If the system is operating well, the bacterial masses, floc, will be in large clumps, and few small masses or single dispersed cells will be present. The nature of the higher forms of animal life in the sludge is also important. McKinney and Gram (21) discuss completely the importance of these higher forms. In general, however, the presence of stalked ciliated protozoa and rotifers is a good indication of a well-operating pilot plant. With a little experience, the general condition of an activated sludge can be rapidly determined by microscopic examination. The absence of higher animal forms or the presence of filamentous bacteria or fungi do not necessarily mean trouble, but the researcher should re-examine the pilot plant to see what is causing this situation.

4. Soluble chemical oxygen demand of the effluent. The COD of the membrane filtrate of a mixed liquor sample taken at the end of the aeration period will be a measure of nearly all of the soluble organic matter leaving the pilot plant. There are only three ways COD may be satisfied in this type of a pilot plant. One, chemical oxidation, such as sulfite being oxidized to sulfate, may occur. This possibility may be eliminated by measuring the COD of the raw waste before and after 15 min of plain aeration. Two, the waste may be blown out of solution. This is of particular importance when dealing with volatile substances such as alcohols, aldehydes, ketones, ethers, and benzene. This possibility may be eliminated by measuring the COD of the raw waste before and after 23 hr of plain aeration. If these two possibilities of COD satisfaction are checked and eliminated, then the COD reduction must be due to the third alternative, biological degradation. Therefore, the change in COD through the pilot plant is the biologically treatable portion of the industrial waste. Of course, if alternatives one or two are also present they must be subtracted from the change in COD, as they are not biological processes.

The 5-day BOD has traditionally been used for design of waste treatment plants and the use of COD has been criticized because it is a chemical test and, therefore, does not measure what the microorganisms will remove. This criticism would be valid if only the COD of the raw waste were considered, but the change in soluble COD through an activated sludge pilot plant tells exactly what portion of the organic matter in the industrial waste is being removed and, discounting special cases, this removal is due to biological action only. The 5-day BOD test will not give this information.

One problem with the BOD test is the use of sewage or unacclimated organisms as seed. This may be corrected by the use of acclimated activated sludge mixed liquor as seed. Since activated sludge contains about 100 times as many organisms as sewage per unit volume, 1 ml of mixed liquor per 20 l of dilution water is more than equal to 40 ml of settled sewage in the same volume. Even with the use of acclimated organisms, however, the problem remains that the 5-day BOD measures only part of the biologically treatable organic matter in the industrial waste. If the ultimate BOD of the raw waste with acclimated organisms were known, this would be a measure of all of the biologically oxidizable material in the waste and would be equal to the change in soluble COD through the pilot plant. But the ultimate BOD is difficult to determine and requires a knowledge of the rate constant k_1. The change in soluble COD through the pilot plant is very easy to determine, is not affected by

TABLE II.—COD and BOD* Data Obtained from Pilot-Plant Studies on Diluted Sulfite Waste Liquor

Item	COD Data (mg/l)	BOD Data (mg/l)
Raw waste	2,770	528
Soluble oxygen demand of effl.	1,770	25
Change in soluble oxygen demand	1,000	503

* k_1 = 0.065/day, raw waste. Ult. BOD of raw waste = 1,000 mg/l.

the errors inherent in the BOD test, and gives the desired information.

Table II gives some BOD and COD data to illustrate the problem. If the size of an aeration tank of a complete mixing activated sludge plant with a design criterion of 60 lb of biologically oxidizable organic matter, as oxygen, per 1,000 cu ft of aeration capacity per day (McKinney *et al.* (22)) were to be determined to treat 1 mgd of this waste, which result should be used? The COD of the raw waste should not be used as the waste contains some biologically inert material. The 5-day BOD of the raw waste measures only a percentage of the biologically oxidizable material and, therefore, should not be used either. The correct value is the change in soluble COD. If the k_1 value were known to be 0.065, the ultimate BOD of the raw waste could be calculated as 1,000 mg/l and this value used for design purposes, but the evaluation of the rate constant k_1 is a difficult, time-consuming, and inaccurate procedure. The change in soluble of COD of 1,000 mg/l indicates the presence of 8,340 lb of biologically oxidizable organics, as oxygen, per day in the waste stream. This requires an aeration capacity of 139,000 cu ft. This waste is 36 per cent biologically treatable.

A useful modification of the COD test to increase its accuracy when only small samples are available is as follows. The basic idea is to divide everything in the conventional test by five. In the standard COD test, the maximum sample is 50 ml. Samples less than 50 ml are made up to 50 ml with distilled water. Twenty-five ml of 0.25N potassium dichromate, 75 ml of concentrated sulfuric acid, and 1 g of silver sulfate are also used. The excess potassium dichromate is titrated with approximately 0.25N ferrous ammonium sulfate, standardized daily. The calculation for COD is: (blank-titration) × (40) × (strength factor) for a 50-ml sample. But if 10 ml were the largest available sample, the multiplying factor increases from 40 to 200. If effluent COD's are being measured, typical values of COD of 50 to 70 mg/l require the blank-titration factor to be about from 0.25 to 0.35 ml. This small difference is very inaccurate.

In the modified COD test, the maximum sample size is 10 ml. Any sample less than 10 ml is made up to 10 ml with distilled water. Five ml of 0.25N potassium dichromate, 15 ml of concentrated sulfuric acid, and 0.2 g of silver sulfate are also used. The excess potassium dichromate is titrated with approximately 0.05N ferrous ammonium sulfate, standardized daily. About 25 ml of titrant is required for standardization. The calculation for COD is: (Blank-titration) × (40) × (strength factor) for a 10-ml sample. A COD of 50 mg/l will be derived from a blank-titration factor of about 1.25 ml. This value, because it is much larger, is more accurate than the 0.25 value obtained with the conventional COD test. Moreover, the modified method is fully as accurate with respect to recovery of organics as the conventional method is. If there is any doubt about the recovery of organics, the two-hour reflux period may be lengthened.

A few additional points of interest about this useful test are listed below:

1. The standard is prepared with 5 ml of 0.25N potassium dichromate, 15 ml of concentrated sulfuric acid, and

about 150 ml of distilled water in a 250-ml Erlenmeyer flask.

2. Four drops of Ferroin indicator are used in each sample.

3. The titration of the distilled water blank is so consistently 0.2 ml less than the titration of the standard, that no blank need be run, a value of titration 0.2 ml less than the standard is used.

4. After refluxing, the samples may be diluted to about 150 ml with distilled water right in the 250 ml COD flask. No transfer to another flask is necessary.

5. Thirty grams of silver sulfate may be dissolved in a 9-lb bottle of concentrated sulfuric acid, making the concentration 0.2 g per 15 ml or 1 g per 75 ml of silver sulfate. Solution of silver sulfate requires overnight standing. This avoids the weighing of silver sulfate for each test and assures that the silver sulfate is always present in the COD flask.

Replicate Runs

Biological tests usually do not duplicate data exactly, but laboratory tests on replicate units indicate that the trends of the data will be the same, even though the individual points will not check. Therefore, replicate runs are not necessary.

Length of Studies

It is not possible to say how long complete acclimation will take. If there is a mixture of organics in the raw waste, secondary acclimation may take a long time. Testing is normally stopped after the effluent quality is constant for at least three weeks. Usually 5 to 10 weeks is an ample testing period.

Conclusions

Based on laboratory studies, the following conclusions have been reached:

1. The raw waste should be analyzed for COD, 5-day BOD, nitrogen content, pH, acid-base titration curve, and, if buffer is not required, phosphorus content.

2. Batch-fed, fill-and-draw pilot plants should be used with a capacity of 1.5 l. Complete sludge return should be employed.

3. An aeration period of 23 hr and a settling time of 1 hr should be used.

4. The feeding criteria should be 1,000 mg of COD removed per day.

5. Phosphate buffer should be used to hold the pH between 6.5 to 8.0.

6. Proper acclimation procedures must be used.

7. The control tests should include total and volatile mixed liquor suspended solids, pH, microscopic examination, and soluble COD in the effluent.

8. Replicate runs are not needed.

9. Studies should be run until effluent quality has been constant for three weeks.

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Water Pollution Control Federation

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WASTE CONTROL IN A SOUTHERN PAPER MILL*

By Frank J. Coogan

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Springhill Mill of the International Paper Company was completed in 1938. It is located 40 miles northwest of Shreveport, Louisiana, on Bodcau Bayou, a small stream that has a very low summer and fall flow. The plant site is about two miles from Bodcau Bayou, and Cypress Creek flows from the plant site into Bodcau.

The wood used in the Kraft Process is relatively young pine. The wood diameter most suitable is from 6 to 10 in., so it takes, under ideal conditions, 10 to 12 years to grow wood for use in this process. The wood produced in this part of the South is Loblolly or short leaf pine and wood is received from a 200-mile radius around Springhill. The length of pulpwood is about 5 ft and the smallest diameter can be about 4 in. The wood is brought into the millyard on trucks or on freight cars and is unloaded and piled. The wood is usually rotated about every 40 days. The first step in the preparation of the wood is that of bark removal. The wood conveyors carry the wood sticks and empty them into the barking drums which are cylindrical units about 12 ft in diameter and about 45 ft long. The wood is freed from bark simply by the rubbing and pounding action of the sticks on each other and on the toothed rings that are carried on the inside of the barking drums. The barked sticks fall out of the drums onto a conveyor and are carried to the chippers. The chippers are cylindrical plates or discs through which knife edges protrude. The knives are placed at right angles to the axis of the disc and are spaced at even intervals along the periphery. The ideal chips are from ½ to 1 in. in length along the grain of the wood. The chips, as prepared, are cut at an angle of 45° to the grain of the wood. This permits penetration of the cooking chemical.

Pulping Process

The chips are fed into cylindrical digesters along with an alkali cooking liquor. The cooking liquor consists principally of caustic soda and sodium sulfide. The presence of the sulfide accounts for the unusual strength possessed by pulps made by this process. The digester is capped and live steam is then turned into the bottom of the digester. This steam serves to heat the contents of the digester to 345°F and 110-lb pressure so that the non-cellulose material is dissolved out of the wood by the caustic component of the alkaline cooking liquor. The undissolved portion consists of cellulose fiber with a certain amount of non-cellulose material and the dissolved materials are lignin and carbohydrates. At this point in the process turpentine vapors are released and subsequently condensed and recovered.

At the end of the cooking period, the contents of the digester are blown by steam pressure into a blow tank. The pressure forces out the digester contents, consisting of pulp and spent liquor; and this action also serves to break up fibers as a result of the sudden drop of the pressure from 100 lb down to atmospheric pressure. The pulp mixture as blown contains the pulp fiber and spent cooking liquors. The pulp is washed free of the spent or black liquor

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on vacuum-type washers. This consists of diluting the stock with liquor and pumping to vats around a revolving drum. This drum, which is horizontal, has a covering of fine wire screen. The pulp forms a thick mat on the drum which travels continuously and at the same time the liquor solution is pulled through the pulp mat to liquor tanks. This operation is repeated several times and each time the diluting liquor is progressively weaker. Water is sprayed on the pulp for the final washing.

The pulp is discharged into a chest and then pumped to the screen room. Here the pulp is diluted and passed through revolving screens which remove the partially cooked pieces of wood and undigested knots. These screens have holes of such size that the pulp fiber passes through and the larger uncooked fiber is retained. This washed pulp is then thickened or dewatered and is ready to be pumped to the paper mill.

At this point the material is unbleached kraft pulp and is brown in color. This is the pulp used for making board for shipping containers and also for making kraft paper such as is used in grocery bags.

Bleaching and Washing

For bleaching, the brown pulp is first prepared as above except that it is usually digested to a greater degree in order to remove more lignin and other non-cellulose materials. Bleaching is then accomplished by treating this pulp with chlorine gas or chlorine dioxide followed by treatment with caustic soda to remove chlorinated compounds and oxidation products. Each of the above steps is followed by thorough washings to remove impurities. This white pulp is now ready for the paper mill and the production of white grade paper.

In the washing stage mentioned above, the spent chemicals are recovered. These spent chemicals are at a concentration of about 16-per cent solids. These solids are then thickened in vacuum evaporators to a concentration of 50 per cent. This heavy viscous liquor is then burned in a recovery furnace and salt cake or sodium sulfate is mixed with the liquor before burning. The salt cake furnishes the soda makeup, hence this process is often called the sulfate process. The salt cake or sodium sulfate is simply the source of soda and as such is not a pulping agent. The carbon in the black liquor reacts with sodium sulfate to form sodium sulfide. The sodium salts in sodium sulfide, sodium carbonate, and sodium hydroxide are recovered as smelt. This smelt is dissolved in weak wash water, treated with lime to convert the carbonate to caustic soda thus making white or cooking liquor. This accomplishes the liquor cycle.

Briefly, the liquor cycle may be described as follows: (*a*) white liquor to digester, (*b*) spent liquor to evaporators for concentration before being sent to the recovery furnace where sodium sulfate is added, (*c*) smelt to the dissolving tank, resulting in uncausticized liquor, (*d*) addition of lime, (*e*) clarification of the liquor, (*f*) cooking liquor or white liquor to the digester, and (*g*) the spent lime with the sludge solids to the lime kiln where the lime is heated and the lime is regenerated. A modern pulp and paper mill will recover 92 per cent of chemicals used in the process.

Paper Production

The pulp, either bleached or unbleached, is diluted with fresh water, is put across the fourdrinier which makes a thin sheet of paper and then is put through the press rolls, the drying rolls, the calender stacks and more drying rolls and more calender stacks and finally comes out the other end as paper familiar to all.

Sources of Waste

There are four sources of waste in this process.

1. Waste from the pulp mill, which in a modern pulp and paper mill is relatively insignificant.
2. Some of the black liquor that is left in the pulp after it is passed over the brownstock washers comes out of the pulp in the wet room.
3. The bleachery is probably the source of the most concentrated and hardest to handle waste from a mill. The caustic rinse that follows the bleaching process produces a waste which is very strong in color, very high in BOD and it is not subject to reuse.
4. There is some waste from the machine room where the pulp is made into paper.

Types of Production

This plant was originally built to manufacture bleached pulp for the rayon industry and heavy board or brown paper for corrugated shipping containers. But with product developments and new techniques, production emphasis was shifted to kraft container board and fine grades of bleached kraft paper and board. This was a significant development for the South, for many of these grades, notably stock for milk containers had never been made from all kraft pulp or on fourdrinier machines. Six months after the conversion to these products, Springhill was producing fine, heavy weight, bleached kraft grades which were soon to become the standard for the industry. Here, also, are made tag stocks, IBM paper, envelope stock, government post card stock, unbleached kraft paper for multiwall bags, and machine-dried pulp for rayon mills. In other words, Springhill is a highly diversified, large pulp and paper mill with a present capacity of 1,470 tons of paper per day.

Waste Handling

The original waste disposal methods utilized from the start of operations until July 1940 consisted of allowing wastewater to flow through the basin into Bodcau whenever there was any flow in the Bayou. This disposal system resulted in numerous complaints being filed with the company. In 1940 a dilution control system was adopted whereby a ratio of waste to dilution water was used as a guide while discharging. In 1942 high stages in the Red River held water up in Bodcau Bayou and another series of complaints were received which resulted in another change in the method of discharge. The new method called for an annual discharge during the winter months with smaller amounts of waste being discharged during the first few days in order that the fish might move out of Bodcau into Red River as well as into tributaries of Bodcau. This method was used until the end of the 1948–1949 discharge. Since that time a combination of the annual discharge method and the dilution ratio method has been used. Waste is discharged only in the winter and only in amounts that would not result in lowering the oxygen content of Bayou Bodcau below 2½ mg/l. Wastes produced during other times of the year are held in a series of lagoons and are described later.

Action Taken Against Waste Discharge

From 1938 to 1948 the waste discharges caused a great deal of trouble. Many civil suits for damages were filed in state courts and were transferred to and tried in federal courts. Damages were assessed against the Company. It was found necessary to spend large sums of money to purchase flowage rights from various land owners located on Bodcau Bayou below the mill. Much adverse publicity was given to the mill and community relations were poor. The Louisiana Stream Control

Commission held several meetings between 1942 and 1945 to consider the problem of the discharge of effluent from the Springhill Mill into Bodcau Bayou. In 1942 the Commission adopted standards setting forth the amount of dissolved oxygen that must be maintained in Bodcau Bayou during the waste discharge period and set this amount as 2½ mg/l. In 1945 the Stream Control Commission filed an injunctive suit in District Court to enjoin the discharge of waste from the mill in such a manner to be injurious to fish and wild life. Following several meetings between members of the Commission and company personnel, it was agreed that further action would be withheld on the suit. The suit was finally dismissed in 1952.

Effects of Waste on Land and Cattle

After 1949 when the present discharge system was put into operation an intensive effort was made to improve the Company's community relations.

To learn whether the plant effluent was harmful to cattle, long-range experiments were conducted on the effects of wastewater on cattle. These experiments were conducted on fenced lands immediately adjacent to Basin No. 1. The experiments were designed to investigate the effects of paper mill wastes on (*a*) the growth of field crops, growing on soil that had been flooded with wastewater, (*b*) cattle that had been drinking the water, and (*c*) cattle that had grazed on pastures that had been flooded with wastewater.

Results of the study indicated that the soil prior to and after the annual applications of 3, 6, and 12 in. of undiluted paper mill wastewater for 5 consecutive years showed no significant reductions in the yields of corn, cotton, or a meadow mixture of Dallas grass, white clover, and lespedeza. Soil analyses at the conclusion of these experiments showed no build-up of soluble salts in the soil and showed no marked increase in the pH of the soil from treatment of the various rates of paper mill wastewater.

Results of using fresh well water as drinking water for steers being grazed on improved pasture were somewhat, but not significantly, better than the results from the use of paper mill wastewater when measured on the basis of the average production of beef per steer. Observations by veterinarians and meat inspectors on the steers at the time of slaughter showed no major difference in the health of steers using wastewater and those using fresh well water.

These studies were believed to offer conclusive evidence that paper mill wastes are not toxic to crops and cattle.

Waste Discharge Methods Now in Use

Beginning March 1 when all gates are closed and all lagoons empty, waste from the mill (averaging about 22,000 gpm) is discharged to the first lagoon. The second and third basins and Murray Annex are being used for fresh water storage. The water is being pumped from Bodcau Bayou either from Lake Erling or as a result of rain which normally comes at that time of the year. This pattern is followed until September.

In September when the first basin is nearly full of waste the second and third basins are emptied of fresh water and the first basin is discharged into the second and third basins. It has not been found necessary to utilize Murray Annex as a waste disposal basin although it was constructed for that use. About the first of November the discharge of waste from the second and third basins is usually begun, using a ratio of about 4 or 5 to 1. The waste has a BOD of 20 mg/l. Lake Erling supplies the dilution water at this time because of practically no flow in the Bayou. Stream reports are made daily. There are 16 stations

checked each day by three waste disposal inspectors. The locations checked vary from points above the mill to Lake Erling and almost down to the Red River by the time the waste gets to that point. The ideal condition to discharge is when the Bayou is full. That means that no water gets into the woods, no pools are formed, and no backwaters are formed to flood back when the water drops in the Bayou.

Duck Hunting Downstream

Bodcau Dam, a large government reservoir, is located below the mill about 16 or 20 miles. The Louisiana Wildlife and Fisheries Commission has provided a place in this area for duck hunting, which is convenient to hunters from northwest Louisiana. Inasmuch as there is little or no water normally available at this time to flood the area, the wastewater from the paper company is used to flood this duck hunting area, which covers about 1,600 acres and is from one to three feet deep. Waste discharge is arranged for around the first of November in order that the duck hunters might have some water by the time the first flights begin to come down.

Summary

The key actions taken to improve the situation in Bodcau could be divided into two parts: (*a*) the changes that were made inside the mill and (*b*) the changes that were made in the disposal system and in the supply of fresh water. Major changes were made inside the mill to cut down on the amount and concentration of waste that was being discharged to the basin and to the Bayou. The installation of the brownstock washers in 1945 cut the BOD of the effluent almost in half. The assignment of the waste disposal responsibilities to a technical department within the mill in the early days had a great deal to do with bringing about the improved conditions. Another factor was the construction of Lake Erling. This lake provided a source of dilution water for use during the winter.

In summary, a description has been given of the wastewater problems at the International Paper Company's Springhill, Louisiana, plant. In this 1,470-ton mill, with a 600-ton bleaching capacity, located on a water course with little or no flow during the summer and fall months, closing the system inside and the provision of waste holding and outside the mill and basins for the warmer part of the year, followed by controlled discharge to the available watercourse during the winter have provided an equitable solution to the problem.

FISH KILLS

The U. S. Public Health Service has begun a nationwide system of reporting fish kills. State fish and game organizations have been asked to report kills directly to the Service, and the U. S. Fish and Wildlife Service is cooperating in the project.

This is the first time a national tabulation of the numbers of fish kills has been attempted. Quarterly and annual reports of kills, listing numbers, locations, and causes, when known, will be distributed.

SUBMARINE DISPERSAL SYSTEM FOR TREATED CHEMICAL WASTES *

By J. M. Gill, J. H. Huguet, and E. A. Pearson

Plant Manager, Ethyl Corporation, Pittsburg, Calif.; Superintendent, Technical Services, Ethyl Corporation, Baton Rouge, La.; Consulting Engineer, Berkeley, Calif.

As part of a general expansion of production capacity of tetraethyl lead, Ethyl Corporation surveyed a number of possible sites in California and decided to locate near Pittsburg in the San Francisco Bay area. The plant is located near the confluence of New York Slough and the San Joaquin River. Figure 1 shows the location of the plant with respect to the general Sacramento-San Joaquin River delta area and specifically as to New York Slough and the San Joaquin River.

Figure 2 shows the flow diagram of the tetraethyl lead manufacturing process employed at the Pittsburg plant.

Sodium obtained in tank cars is melted and mixed with molten lead to give sodium-lead alloy. The sodium-lead alloy is solidified into a metal flake and is charged into large autoclaves, to which ethyl chloride (also received in tank cars) is then added under closely controlled conditions. These two materials react to form the liquid tetraethyl lead.

$$4\,NaPb + 4(C_2H_5)Cl = (C_2H_5)_4Pb + 3\,Pb + 4\,NaCl$$

By this process the reactive substances, sodium and chlorine, are used to bring together the nonreactive substances, lead and ethylene, and having completed the function, are returned to their stable form—salt.

The next stage of the process is to separate tetraethyl lead from the mixture of salt and lead also formed in the reaction. This is done in a steam still, where steam is fed into the mixture and the tetraethyl lead is distilled out as a vapor, leaving the lead and salt behind. The lead is recovered by washing out the salt, drying in steam dryers, and remelting in a gas-fired furnace. The recovered lead is returned to the process along with fresh lead. Recovery of salt from this dilute brine is not economical, and it is discharged as waste.

The tetraethyl lead vapor from the still is condensed giving crude tetraethyl lead which is then purified and sent to the blending plant where ethylene dichloride and ethylene dibromide are blended in exact quantities to the tetraethyl lead to give the final antiknock mixture. The ethylene dichloride and ethylene dibromide convert the residual lead after combustion in the engine to volatile lead chloride and lead bromide which are removed from the engine along with other exhaust gases.

Receiving Waters

One of the initial steps in locating the plant at Pittsburg was to obtain approval for discharge of residual process and sanitary wastes into the waters of New York Slough. Several meetings and conferences were held with the San Francisco Bay Regional Water Pollution Control Board lead-

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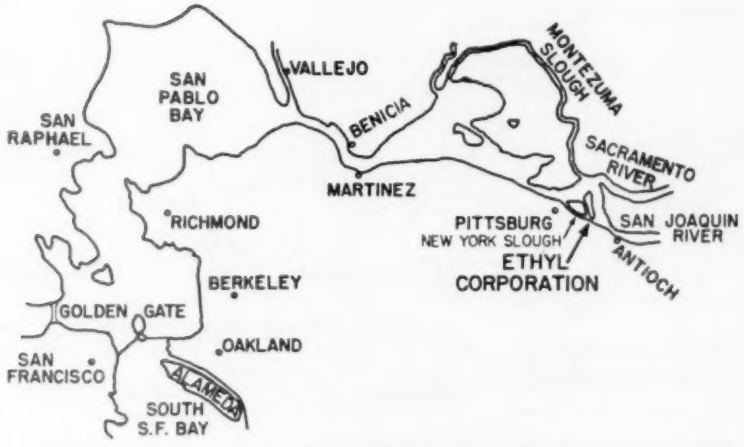

FIGURE 1.—Location map showing Ethyl Corporation in relation to San Francisco Bay area.

ing to establishment of the beneficial uses of receiving waters.

Beneficial Uses

The Regional Pollution Control Board specified that the beneficial uses of the waters of New York Slough and adjoining water courses were as follows:

1. A source of domestic water supply at Antioch and at Mallard Slough during periods of relatively high stream flow.
2. A seasonal source of supply at a point across New York Slough from the Ethyl Corporation plant site for stock watering and irrigation at Winter Island.
3. A migration route for the spawning runs of salmon, shad, steelhead, and striped bass.
4. The propagation of fish and aquatic life.
5. Sport fishing.
6. A source of industrial process and cooling water.
7. Pleasure boating.
8. Navigation.

Water quality criteria were established to protect each of the beneficial uses. These criteria will be discussed later.

Hydrologic and Exchange Characteristics

The amount of water available for dilution of any wastes discharged into New York Slough depends on the physical forces involved in mixing and flushing in the river system. Unquestionably, of greatest import is the net flow of "fresh" water. The major source of this fresh water is the combined surface and subsurface flow of the Sacramento and San Joaquin Rivers.

The State Department of Water Resources (1) has reported that the net flow out of the Sacramento-San Joaquin Delta (near Antioch) varies from a partially regulated maximum during periods of heavy runoff to a minimum of approximately 3,800 cfs during dry weather flow periods. Of this total, 3,300 cfs is considered to be surface inflow from the Sacramento and San Joaquin Rivers and 500 cfs as accretion in the delta. The division of the above flows between New York

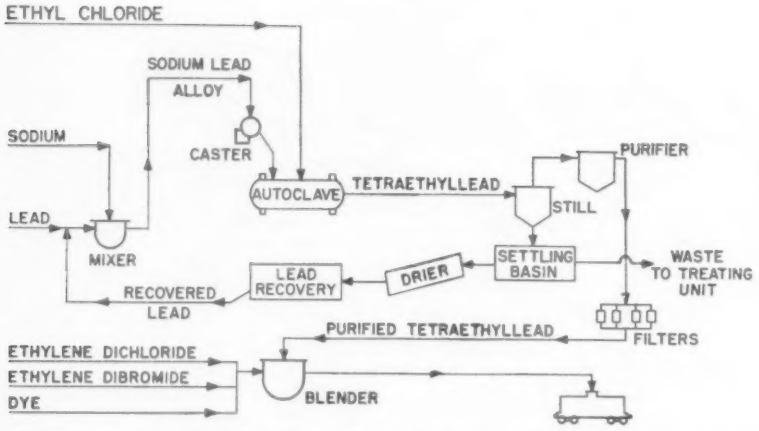

FIGURE 2.—Simplified flow diagram for manufacture of antiknock compound at Pittsburg, Calif., plant of Ethyl Corporation.

Slough and the parallel Sacramento River is not known. However, estimates based on relative hydraulic characteristics of the two sections indicate that the probable minimum net daily flow through New York Slough is about 900 cfs. This flow constitutes the minimum available water for dilution of Ethyl's effluent. If the effluent is dispersed throughout the flow in New York Slough, a minimum dilution ratio of approximately 580 to 1 is effected. It should also be noted that when the net river flow is at this minimum level, the salinity in the Sacramento River at Mallard Slough and at Antioch is too high to permit use of the water for domestic purposes.

No mention has been made of the amount of "new" salt or ocean water available for dilution during low river flow periods. Because this entails consideration of "mixing" or "exchange" coefficients for this section of the delta which are currently not available, no precise estimate can be made of this dilution. However, preliminary crude estimates of the magnitude of tidal exchange indicates that it is probably minor compared to "new" fresh water, but may amount to more than 10 per cent of the new water available for dilution. In any case, tidal exchange provides additional diluting water beyond that considered available from fresh water flow alone during low river flows.

Waste Abatement Facilities

Figure 3 shows components of one of two parallel treatment facilities which receive process streams. For treatment these streams are first conveyed to a large holding or settling basin. Essential functions of the settling basin are to permit recovery of lead and to equalize and blend flows from various operations. The average detention time in the primary settling basin is approximately 90 min. Periodic recovery of lead from the settling basin is planned. The effluent from primary settling goes to a sump and blending basin where automatic pH control is employed to effect optimum flocculation. The waste goes to either one of the two 22-ft diameter conventional upflow clarifiers which are arranged for parallel operation. Ferrous sulfate is added as a flocculating agent to achieve maximum removal of suspended solids. Each of these units is designed to handle the

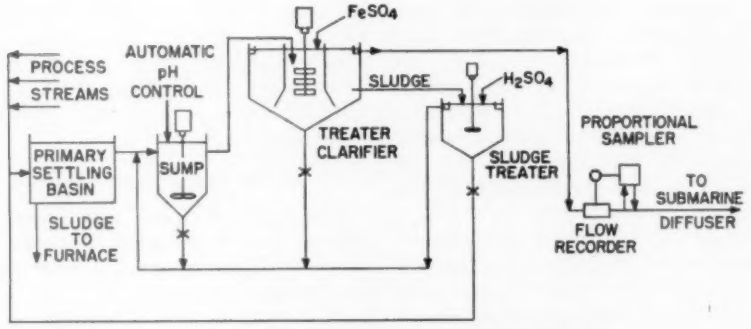

FIGURE 3.—Simplified flow sheet for treatment facilities for antiknock manufacturing wastes.

plant flow; consequently, one unit is always available as a standby. The units are designed for a detention time of approximately 45 min, an overflow rate of about 2,650 gpd/sq ft, and weir loadings of about 15,000 gpd/ft.

The sludge removed from the clarifier is conveyed to a sludge treatment unit. The concentrated solids are returned to the primary settling basin, then to a furnace for recovery. The clarified effluent passes through a continuous flow metering and proportional-composite sampling station prior to discharge via a submarine multiport diffuser to New York Slough.

Sanitary wastes resulting from about 150 persons responsible for plant operation are treated in 4 septic tanks with effluent from the tanks discharged to a chlorine contact chamber designed to provide 30 min detention time. The septic tank effluent is chlorinated to 0.50 mg/l chlorine residual after 30 min contact prior to combining the treated sanitary wastes with the process effluent for discharge through the submarine outfall.

Estimated Effluent Characteristics

One of the difficult assignments confronting management of new plants is to estimate plant or process performance, to say nothing about estimating process effluent characteristics. Data on process and effluent characteristics are available for similar operations within this organization. However, there are always process changes, improvements, or modifications when a new plant is constructed. These changes raise some questions as to what the over-all system characteristics might be, in spite of general similarities in process and production of the same product.

After extensive study and analysis of comparable operations at other plants, an estimate of the Pittsburg plant effluent characteristics was made. Table I presents estimates of the significant characteristics of the treatment unit effluent.

These effluent characteristics are believed to be liberal, particularly the estimated BOD; however, only actual

TABLE I.—Estimated Effluent Characteristics, Pittsburg Plant, for Waste Flow of 1 mgd

Characteristic	Concentration (mg/l)
Total lead	18
Tetraethyl lead	0.36
Metallic lead	12.6
Combined lead	5.0
Sodium chloride	16,700
Sodium sulfate	1,270
Sodium sulfide	18
Ethyl chloride	60
5-Day 20°C BOD	600

plant operation and analysis will provide more precise data on waste characteristics. It should be noted that these data represent the most significant effluent characteristics as evaluated and prescribed in waste discharge requirements, Resolution No. 260, by the San Francisco Bay Regional Water Pollution Control Board.

During preliminary discussions regarding waste discharge requirements, some concern was indicated as to possible or relative toxic characteristics of the effluent. In order to provide information on this point, representative samples of waste simulating the proposed discharge were collected at existing plants and shipped to an independent institution for preliminary bio-assays with fish. Results of the preliminary bio-assays indicated a relatively low level of toxicity. Table II presents the results of preliminary bio-assays for two test fish, three-spined sticklebacks (*Gasterosteus aculeatus aculeatus* L), and juvenile coho (silver) salmon (*Oncorhynchus kisutch* Walbaum) in terms of 24- and 48-hr median tolerance limits. Dilution was with fresh water.

The data in Table II represent the highest toxicity indicated in 5 bio-assay series, three of which were on sticklebacks and two on coho salmon. Also, the waste employed in the bio-assay procedure contained 24 mg/l of total lead as compared to the estimated 18 mg/l in the plant effluent. Preliminary tests indicated a significantly reduced degree of toxicity when sea water was used as the diluent.

In lieu of any better information on the time-concentration-toxicity relationship, a long-term safe concentration of the effluent was assumed to be one-tenth of the 48-hr median tolerance limit as suggested by the ORSANCO Aquatic Life Advisory Committee (2).

TABLE II.—Preliminary Bio-Assay Results

Test Fish	Test Solution Salinity (ppt)	24-Hr TL_m (ppt)	48-Hr TL_m (ppt)
3-Spined stickleback	1.0-3.0	22	14
Coho salmon	1.0-3.0	17	14

Waste Dispersion System

The objective of any waste dispersal system is to distribute or disperse the waste rapidly, uniformly, and effectively in the receiving water. The dispersion system can be considered to depend on two related but distinct physical phenomena: (a) the initial or jet mixing of the waste with the receiving water mass in the immediate proximity of the outlet, and (b) the subsequent transport and mixing or eddy diffusion of the waste-receiving water mixture.

Jet Mixing

Estimates of the dilution achieved by jet mixing were made according to data reported by Pearson (3):

$$S_{oa} = \frac{KL}{D_o}$$

where

S_{oa} = mean dilution of flow from diffuser port,
K = constant (estimates range from 0.23 to 0.33),
L = axial length of jet (depth of outfall), and
D_o = diameter of diffuser ports.

Employing diffuser ports 3⅜ in. in diameter and estimating K at 0.3 indicates an average dilution of 30:1 by the time the waste reaches the surface. In order that this dilution be achieved in a steady state system, a continuous supply of new water must be available at the diffuser.

In order to effect maximum dispersion, the terminal 100 ft of the 360-ft submarine outfall was constructed as a multiport diffuser with 10 ports, 3⅜ in. in diameter, spaced at 10-ft centers. It is assumed that the waste is dis-

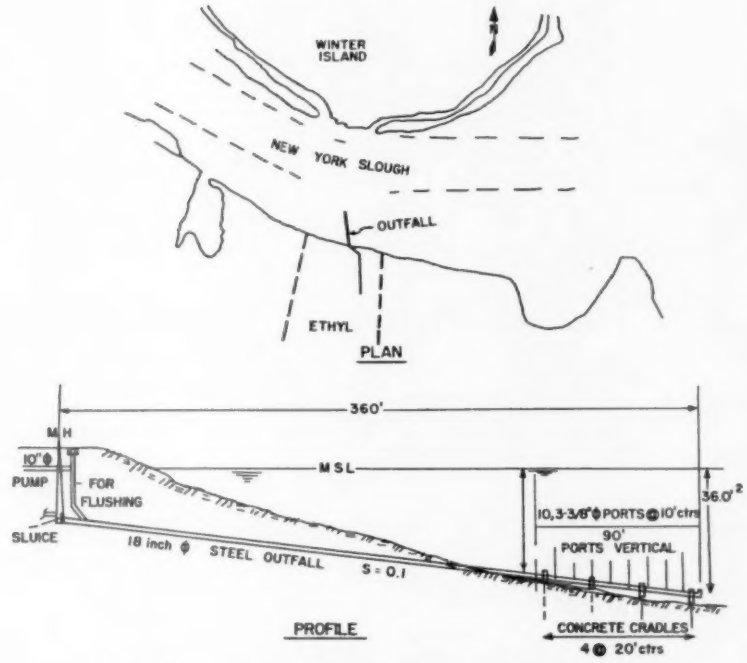

FIGURE 4.—Schematic layout of submarine dispersion system.

persed over the terminal 100 ft of the outfall to an average depth of about 15 ft (one-half water depth) and in a stream with velocities ranging from 1.5 to 2.5 fps during the major portion of the tidal cycle, an average dilution of at least 1,500:1 may be expected.

Eddy Diffusion

Computations were made employing eddy diffusion equations (3)(4) to check the general dispersion of the waste during transport from the outlet. Making judicious estimates of the effective mixing depth and magnitude of the eddy diffusivity coefficient, the estimated dilution at 100 ft from the outfall (point source) is approximately 1,700:1.

While it is recognized that the above computations hold for the major period of the tidal cycle (i.e., when a significant current exists in New York Slough), somewhat lower dilutions may occur at or near the short interval at slack tide. No precise information is available at this time either with respect to the duration of this slack water period in New York Slough or the reduction in dilution resulting therefrom. However, it is believed that the net effect on waste dilution and dispersion in New York Slough will not be significant.

Figure 4 presents a plan and profile of the multiport submarine outfall diffuser system constructed in New York Slough.

Receiving Water Monitoring Program

As a result of conferences with local groups, representatives of the San Francisco Bay Regional Water Pollution Control Board, and the Department of Fish and Game a decision was made to conduct preoperation receiving water quality surveys. Of

primary concern was background lead concentrations in the receiving water as well as in the bottom sediments. However, additional physical, chemical, and limited biological observations were also made.

Water Quality

Figure 5 shows the location of the sampling stations included in the preoperation monitoring program. Water samples were taken at three depths; within 1 to 2 ft of the surface, at middepth, and within 2 to 3 ft of the bottom. Survey trips were conducted on a monthly basis and it is anticipated that 12 sampling trips will be completed by the time the industry starts operation.

Results to date, representing a major portion of the water quality monitoring program are briefly summarized in Table III taken from sample points shown in Figure 5. These data indicate that there is a low but measurable amount of lead in the waters of New York Slough. Although occasional high spot values have been observed, most results are well within the recommended level of 0.05 mg/l total lead.

TABLE III.—Results of Preoperation Water Quality Monitoring Program

Determination	Minimum	Maximum
Temperature (°C)	8.2	23.7
Chlorides (mg/l)	24	3,440
Total lead (mg/l)	nil	0.056
DO (mg/l)	6.8	10.10
BOD (mg/l)	0.51	2.32
Phytoplankton (1,000 cells/l)	100	5,200

The chloride content as expected is highly variable; however, it is of interest to note that chloride values as high as 1,520 mg/l were observed at Antioch during August 1957.

Phytoplankton populations are also variable, but of the order of magnitude that might be expected in estuarial waters. The diversity of principal genera and/or species is not great.

Bottom Sediments

Figure 6 presents a summary tabulation of lead determinations conducted on the bottom sediments. The apparent lead concentration varies from as low as 2 and 3 mg/l to as high as 76 mg/l with some extreme values reported (129 and 250 mg/l) where

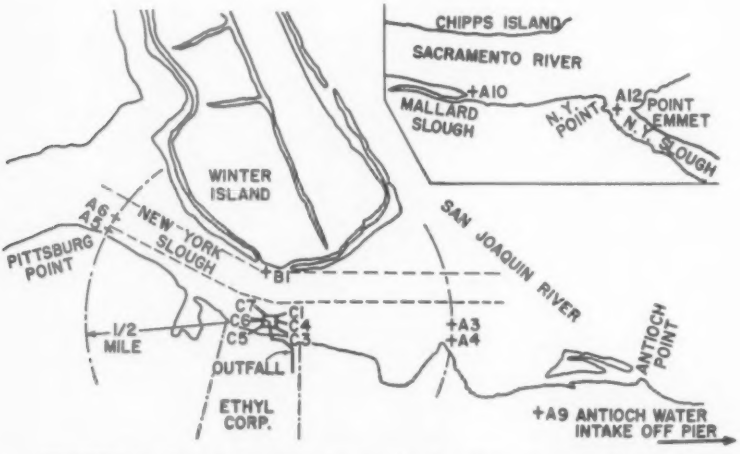

FIGURE 5.—Sample locations for monitoring program as established by Ethyl Corporation.

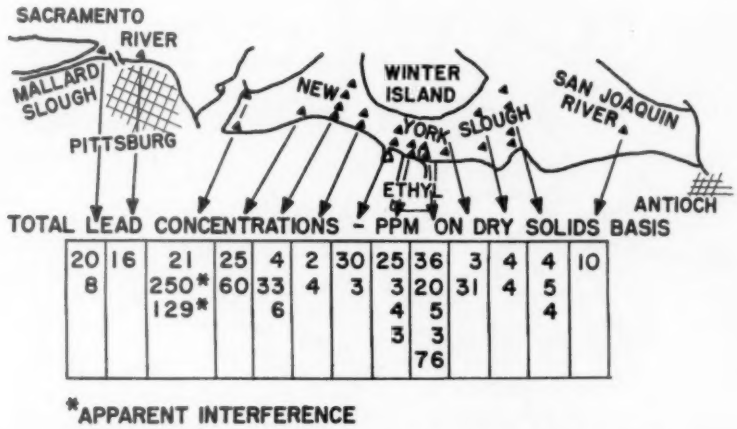

FIGURE 6.—Locations and amounts of lead in bottom sediments.

interference was noted during the analytical procedure. For the most part, the lead content is of the magnitude anticipated and obviously subject to substantial variation. According to Bear (5) the lead content of agricultural and mineral soils ranges from 3 to 300 mg/l with an average of approximately 25 mg/l. Similarly, Hibbard (6) reported a range of lead concentration of 0.5 to 46.0 mg/l with a mean value of approximately 5 mg/l for 21 surface soil samples taken primarily from uncultivated land in California. Therefore, it appears that the values obtained for New York Slough are fairly representative of the lead concentration and variation reported by other investigators for similar soil or sediment samples. The significant variation between samples is also to be expected.

Agency Monitoring Program

The San Francisco Bay Regional Water Pollution Control Board adopted Resolution No. 260 on December 19, 1957, which prescribed requirements for the waste discharge. The Resolution specified limits for waste characteristics in the receiving waters and effluent requirements to protect the beneficial uses. It also specified a monitoring program and sampling schedule to assess adherence to the requirements.

Water quality criteria specified included maximum lead concentrations of 0.05 mg/l one-half mile from the diffuser and median lead concentrations of no greater than 0.3 mg/l from 3 or more representative samples, 100 ft downstream from the diffuser. Additional criteria applied to all the area beyond 100 ft from the geometric center of the diffuser include: (a) ethyl chloride, 10 mg/l, maximum; (b) dissolved oxygen, 5.0 mg/l, minimum; and (c) pH, 6.5, minimum, 8.5, maximum. Increases in chlorides attributable to the waste discharge at Antioch and at the A and O Ferry were limited to 10 mg/l above the 1940–54 normal concentration determined by a correlation of Sacramento River flow to chloride level.

Lead in the bottom sediments 100 ft beyond the geometric center of the diffuser as reported by the median of 5 samples was limited to a maximum concentration of 1 mg/l greater than the median of 5 similar samples taken in a control area located between ½ and ¾ miles from the diffuser. Lead accumulation or increase in the median

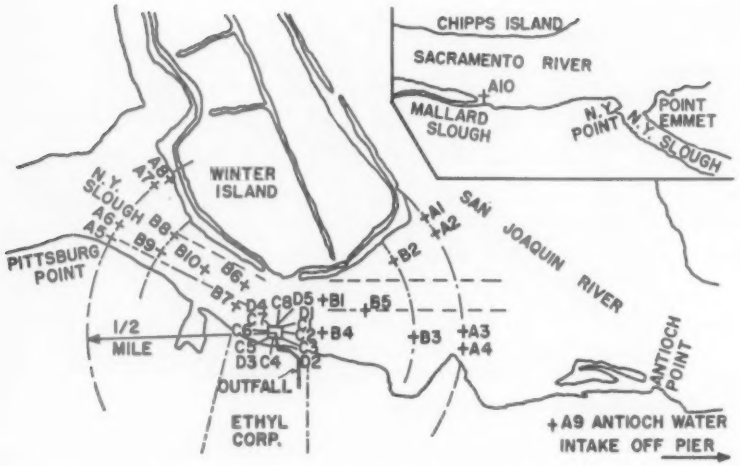

FIGURE 7.—Sample locations for monitoring program as established by the San Francisco Bay Regional Water Pollution Control Board.

of 5 bottom samples was limited to 0.1 mg/l per year maximum.

Figure 7 shows the number of sampling stations and locations specified in Resolution No. 260 for agency monitoring. Stations with prefix "A" are for municipal water quality assessment and are to be sampled and analyzed in accordance with Sacramento River flows (i.e., salinity). It is estimated that these stations will be monitored approximately 26 times the first year to conform to the Resolution. Stations with prefix "C" are for evaluation of the diffuser system and for assessment of water quality as related to the protection of aquatic life and are to be monitored at the same frequency as the "A" stations.

Stations identified as "B" or "D" are for assessment of waste effect on the bottom. The bottom sediment at these, as well as some "A" stations, is to be sampled on a semi-annual basis and is to be analyzed for total lead and other physical characteristics attributed to the waste discharge.

Waste discharge monitoring is also specified in the Resolution and includes daily flow recording and daily analysis of the effluent for total lead, chlorides, ethyl chloride, and pH. More complete analyses are specified on a once per month basis.

The preceding discussion is not intended to be a complete presentation of the Resolution No. 260 Requirements or Monitoring Program. It has been cited in a general way to indicate the extent of the requirements and specifications relating to the waste discharge.

Summary

Consideration is given to the development of waste control facilities, preoperation analyses, and receiving water quality monitoring program for a new chemical plant locating in the San Francisco Bay area. Beneficial uses of the receiving waters were established by the Regional Water Pollution Control Board and water quality criteria was developed in cooperation with interested state and local agencies. Waste control or recovery units were designed to minimize waste discharge. Data regarding the physical, chemical, and biological (bio-assay) characteristics of the proposed effluent were de-

veloped. Hydrologic, exchange, and mixing characteristics of the receiving water were evaluated or appropriate estimates were made. This permitted the rational design of a multiport submarine dispersal system to minimize the effect of the waste on the receiving water.

Preoperation water quality monitoring surveys provided background data for approximately one year prior to plant operation. Summaries of survey data, including total lead in the receiving water and bottom sediments, developed to date by Ethyl Corporation are presented.

A brief review of the Regional Water Pollution Control Discharge Requirements and Monitoring Program is included to indicate the detailed consideration given to the proposed waste discharge.

Careful and exhaustive consideration has been given the proposed discharge to minimize the amount of waste as well as to disperse it with minimal effect on the receiving water. It is believed that the proposed waste control system will meet the objective of an effective waste disposal installation; that is, the waste will have no significant adverse effect on the beneficial uses of New York Slough. To insure the above objectives, restrictive water quality criteria have been established and an extensive monitoring program specified to assess compliance. The work carried out prior to start-up is believed to be in the best interest of both the beneficial users of the water and the industry.

Acknowledgments

The consideration and assistance of the staff of the San Francisco Bay Regional Water Pollution Control Board, State Department of Fish and Game, and the State Department of Public Health are gratefully acknowledged.

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Stream Pollution

TOXICITY OF HEXAVALENT CHROMIUM TO BLUEGILLS *

By Francesco B. Trama † and Richard J. Benoit ‡

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A number of experimental studies have been devoted to the effects of hexavalent chromium salts on fish. Also, there have been a few uncritical compendiums that have led to off-hand estimates of the toxicity range. Moreover, the wide variety of fish species and experimental conditions which have been employed by the various workers makes it difficult to give a meaningful estimate that is generally applicable. Doudoroff and Katz (1) concluded that probably there has never been any unequivocal demonstration that hexavalent chromium below 20 mg/l has any toxic effect on fish. There exists, nevertheless, at least two reports of some degree of toxicity for solutions containing only about 5 mg/l (2) (3).

Earlier Investigations

Trout

Grindley (4) studied the toxicity of solutions of potassium chromate and potassium dichromate to rainbow trout (*Salmo gairdneri* Richardson var. *shasta*) in distilled water. The lowest concentration tested corresponded to 20 mg/l of chromium. With K_2CrO_4 (potassium chromate), the initial pH of the test water was 6.6 and 10 fish survived (maintained equilibrium) for an average of slightly less than 60 hr. At 50 mg/l Cr, the average survival time was approximately 30 hr. At a concentration equivalent to 1,000 mg/l of chromium, the initial pH was 8.0, and the fish maintained equilibrium slightly longer than 1 hr. With potassium dichromate at 20 mg/l Cr, the initial pH of the test water was 5.5 and the average survival time for 10 fish was about 70 hr. At 50 ppm Cr, and at all higher concentrations tested, the pH was even lower, falling to as low as 4.1 at 1,000 mg/l Cr (2,829 mg/l $K_2Cr_2O_7$). For equal chromium concentrations, potassium dichromate was more toxic (average survival time was shorter) than potassium chromate.

Strong solutions of potassium dichromate in distilled water were quite acid in Grindley's work (pH 4.1 to 4.7), and he pointed out that Ellis (5) came to the conclusion that the toxicity of any solution below pH 5.0 is due in part to the acidity. As indicated below, the toxicity of any solution containing hexavalent chromium would be increased by acidity throughout the whole physiological range of pH because of the nature of the dissociation reactions of hexavalent chromium ions.

A number of estimates of certain

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indexes of toxicity could be calculated from the complete data of Grindley (4); the 48-hr TL_m would be about 30 mg/l Cr for trout in distilled or very poorly buffered water. The index would be slightly lower (toxicity slightly higher) for potassium dichromate than for potassium chromate. The 96-hr index concentration would be significantly lower under all conditions. According to Grindley, the unpublished results of a colleague indicated a degree of toxicity to the brown trout (*Salmo trutta* L.) for a solution of potassium dichromate in Nottingham, England, tap water at a concentration equivalent to only 5.2 mg/l Cr. It was no doubt significant that some fish survived this concentration for 48 hr. Grindley concluded that concentrations of hexavalent chromium below 20 mg/l would be non-toxic to rainbow trout. Trout are notably more sensitive to adverse physical and chemical conditions than most other fish, but they are characteristically found in very soft water and may be quite tolerant of distilled water, which would suggest that the use of distilled water in the experiments of Grindley did not invalidate his conclusions. Rushton (6), according to the citation of Doudoroff and Katz (1), indicated that trout failed to recover from a 6-hr exposure to a solution of potassium dichromate containing the equivalent of 35 mg/l Cr, even when returned to fresh water.

Schiffman and Fromm (7) performed carefully controlled experiments on the rainbow trout in hard water (hardness, 334 mg/l; alkalinity, 204 mg/l; pH, 8.5 to 8.8). Using $K_2Cr_2O_7$ as the salt, they determined that the 24-hr TL_m concentration was 100 mg/l Cr, but exposure of the fish to only 20 mg/l or even as low as 2 mg/l Cr caused significant pathological changes including a striking response in hematocrit value. As was the case in their earlier work with largemouth bass, Fromm and Schiffman (8) found no significant damage to gills. Many workers have noted that heavy metals cause coagulation of gill mucus and have implicated this change as the cause of death from heavy metal poisoning in fish. It was not surprising that chromate, being an anion, should differ in its specific physiological action. For largemouth bass, Fromm and Schiffman (8) determined that the 48-hr TL_m was 195 mg/l Cr, but they observed that less than 100 mg/l invariably caused significant physiological changes in the intestine, and death in 80 hr. Fishes exposed to 65 mg/l Cr survived for 6 days.

Goldfish

Addendum No. 1 (9) to California Water Pollution Control Board Publication No. 3 (10) cited the work of Martin and Rostenbach (11) who indicated that 10 mg/l hexavalent chromium, as $Na_2Cr_2O_7$, was only slightly hazardous to fish. No details were given in the summary citation, and Martin and Rostenbach gave only a very rough estimate of the quality of the water that received wastes from a synthetic rubber plant. The estimate seemed to have been based solely on the results of Ellis (5), who determined that goldfish in hard water survived 100 mg/l Cr (hexavalent) for 108 hr and 500 mg/l for 72 hr.

The extensive work of Ellis (5) on toxicity of acids as well as the results of his tests involving chromate are pertinent. He found that goldfish could survive for four days in river water reduced, respectively, to pH 4.0 with sulfuric acid, to pH 4.5 with hydrochloric or citric acid, 4.6 with lactic acid, and 4.9 with nitric or tartaric acids. He concluded, however, that acidity near the magnitude of pH 4.0 would be lethal under any set of chemical circumstances if the acidity were maintained. Trama (12) in a study of the pH tolerance of the bluegill found the absolute lower limit of tolerance to be 4.00 ± 0.15 pH units. Ellis stated simply that all concentra-

tions more acid than pH 4.0 were lethal to goldfish. This would appear to be a valid conclusion.

Ellis (5) included "chromic acid" in the section of his paper on acids. Undoubtedly, he referred to chromium trioxide (CrO_3) or as it is sometimes called, chromic anhydride. He determined that goldfish survived for more than 96 hr in a solution of 100 mg/l CrO_3 (52 mg/l Cr) in hard water. The same concentration in very soft water killed goldfish in 30 to 35 min. This very important fact seems to be overlooked by some reviewers. Ellis did not include data for potassium dichromate in his many tables, but stated in summary that goldfish survived 100 ppm $K_2Cr_2O_7$ (35 mg/l Cr) in hard water for more than 108 hr, but 500 ppm (176 mg/l Cr) caused death in the same hard water in 72 hr.

Sunfish

Klassen *et al.* (13) studied the toxicity of an electroplating waste containing hexavalent chromium using various fish of the sunfish family including bluegills and a very hard dilution water (about 300 mg/l). Undoubtedly, the waste contained other toxic materials in addition to chromium which probably contributed to the extreme variability reported. Doudoroff and Katz (1) did not accept the explanation of Klassen *et al.* (13) that small variations in temperature could explain the discrepancies. For the purposes of this review, perhaps only the survival details would be of value. In the tests of Klassen *et al.* (13), sunfish survived as long as 20 days in a dilution of the waste in hard water containing 45 mg/l Cr, and as long as 5 days in a dilution containing 68 mg/l Cr.

Abegg (14) gave the 24-hr TL_m of sodium chromate and sodium dichromate for small bluegills (4 to 10 cm) in a synthetic dilution water designed to approximate the chemical composition for the average of the entire United States. It has been recommended by Hart *et al.* (15) that such a water be used as a standard for fish toxicity testing. The water would have less than 500 mg/l total solids, a hardness between 75 and 150 mg/l, alkalinity between 60 and 120 mg/l, and a sulfate content between 20 and 50 mg/l. Using this water and a controlled temperature of 21°C, the 24-hr TL_m was determined to be 290 mg/l Cr when sodium dichromate was used, and 300 mg/l Cr when sodium chromate was used. Abegg indicated that larger fish (20 to 35 g) survived longer than the smaller fish, whose weights were not given, but which probably would have varied in weight between about 1 and 10 grams.

Salmon

The report of the Washington Department of Fisheries for 1954 (16) cited results obtained at the Deception Pass marine research station on juvenile or young salmor in both fresh and salt water. The results were expressed in terms of the "minimum lethal concentration." For hexavalent chromium, the results given were less than 10 mg/l Cr in fresh water and 17.8 in sea water. These values differed markedly from those reported by Jones (17) for trivalent chromium using sticklebacks (*Gasterosteus aculeatus* L.), and from the results of other workers cited in Doudoroff and Katz (1). Using a very soft tap water, Jones found that only 2 mg/l of trivalent chromium (as the sulfate) was lethal to sticklebacks in 48 hr. The pH of the solution was 5.7, which the fish would ordinarily tolerate "indefinitely." Oshima (18) found that 5.2 mg/l of trivalent chromium as $KCr(SO_4)_2$ killed small eels in less than 20 hr. LeClerc and Devlaminck (19) reported the failure of minnows to survive exposure to 40 mg/l of trivalent chromium in distilled water for as long as 6 hr. There can be little doubt that the hardness of the dilution water used had an effect on

the toxicity of hexavalent chromium salts (chromates), and it was probably even more important in evaluating the toxicity of trivalent chromium which can undergo hydrolysis and precipitate as the hydroxide in the presence of alkaline reserve. It is also true that a comparison is being made between an anion and a cation.

Microorganisms

Meredith and Ingols (20) and Fetner and Ingols (21) note that chromates are extremely toxic to obligate anaerobes. On the other hand, aerobic microorganisms seem to be extremely sensitive to trivalent chromium. Morgan and Lackey (22) studied the effect of trivalent chromium and divalent copper on BOD. Trivalent chromium reduced BOD to less than one-half the control value at only 3 mg/l Cr, and to nearly zero at 20 mg/l. The reduction in BOD no doubt was merely a reflection of the inhibition of oxygen absorption and, probably, growth by the aerobic organisms present in the inoculum used in the tests. It was also of interest that the addition of a strong chelating agent, ethylenediaminetetraacetic acid (EDTA), completely overcame the inhibiting effect of trivalent chromium. It is not surprising that a non-metabolizable chelator like EDTA should reduce heavy metal toxicity, but it must be remembered that hexavalent chromium in solution exists in various anionic forms, not as a cation subject to chelation by EDTA in the ordinary way. Preliminary studies by Benoit on the toxicity of chromium salts to a rapidly growing strain of the green alga *Chlorella sp.* have shown hexavalent chromium to be markedly more toxic than trivalent chromium in a growth medium with a hardness of about 60 mg/l. No inhibition of the growth of the alga was noted at 3.0 mg/l trivalent chromium or at any lower concentration tested. Inhibition was complete at 30 mg/l, the next higher concentration tested. With hexavalent chromium there was marked inhibition of growth at 3.0 mg/l Cr, and even some slight inhibition at 0.3 mg/l. Inhibition was complete at 6.0 mg/l and at all higher concentrations tested. Based on existing knowledge, it is probably not safe to generalize concerning the relative toxicity of trivalent and hexavalent chromium to diverse organisms. It would seem, in fact, that even among the fishes there are marked differences in sensitivity. In any case, as far as industrial wastes are concerned, hexavalent chromium (chromates) is of much commoner occurrence.

Conclusions from Other Findings

It is difficult to conclude anything with confidence about the toxicity of hexavalent chromium from the results of the studies cited above. For one thing, the various tests were done under a wide variety of conditions. The resultant lack of accord among the workers would seem to be a hearty recommendation for the use of standard conditions as outlined, for example, in Doudoroff *et al.* (23). It would be true, however, that standard conditions might not correspond with any given detail of a natural system. If a particular situation from nature were under study, the best procedure might be to modify test conditions to match the natural system as closely as possible. In any case, there would be real heuristic utility in having data for both standard conditions and for particular situations.

Materials and Methods

In this investigation, 5-gal widemouth pyrex bottles fitted with a rubber stopper and aeration tube were used as testing containers. The temperature was maintained in a water bath at 20°C ± 1°C over the 96-hr test period. Compressed air at an approximate rate of 200 bubbles per minute was delivered at the bottom of the bottles to insure an adequate

TABLE I.—Composition of Dilution Water

Constituent	Concentration (mg/l)
KCl	20
Na_2SiO_3	20
$NaHCO_3$	40
$MgSO_4 \cdot 7H_2O$	40
$Ca(NO_3)_2$	30
$CaCO_3$	10
K_2HPO_4	2
Ferric citrate–citric acid, equimolar to give (as Fe)	0.4

dissolved oxygen content. The oxygen content was not determined except in controls, since hexavalent chromium interferes with the oxygen determination by the standard Winkler method. The modification of the Winkler method for use in the presence of chromate as suggested by Fromm and Schiffman (8) did not become known to the authors until after the completion of the tests. In this modification, chromate is simply precipitated with barium chloride before the addition of the manganous chloride and potassium iodide. The dissolved oxygen in the several controls never fell below 6.0 mg/l.

Medium

All tests were run in a dilution water slightly modified from algal culture medium No. 14 of Chu (24). The dilution water was made with distilled water and reagent grade chemicals (Table I).

Each salt was pipetted individually, in the order shown in Table I, from a concentrated stock solution to 5 gal of distilled water. The solution was then diluted to 20.4 l with distilled water. Each container was aerated for 65 hr prior to introducing the fish. One hour before placing the fish in the test container, the desired quantity of C.P. chromium salt was added to the water.

The dilution medium is higher in phosphate and nitrate than natural waters, but in many of its characteristics it is similar to the average composition of creek waters of the Atlantic Coast (25). Some measure of its composition is shown in Table II.

Fish

The test fish, the common bluegill *Lepomis macrochirus* Raf., purchased from a fish hatchery, were free from any visible disease. They were acclimated 7 days in the dilution water at 20°C ± 1°C. All were fed daily with chopped, cooked shrimp, but not within the 43 hr preceding the test period nor during the testing period. It may be noted that bluegills have been kept in the authors' laboratory for as long as one month with no apparent ill effects. Sizes ranged from 5 to 9 cm in total length, with weights of 1 to 9 g. Following the recommendation of Doudoroff *et al.* (23), no fish varied more than 50 per cent in total length from any other fish in any one test container. Ten fish were placed in each container. All tests were run in duplicate.

The criterion of the death point was the cessation of gill movements. Dead fish were removed every 24 hr. Those surviving the test period were killed and discarded.

A control was run with every series of tests at a rate of 10 controls per 100 test fish. Controls were kept under conditions identical to test fish. No deaths occurred in any control container.

Immediately before introducing the fish and at the end of 24, 48, 72, and 96 hr, the pH was determined.

Results

The hexavalent chromium salts added to the weakly buffered dilution water poised the initial pH. When the potassium dichromate concentration was 155 mg/l, the pH ranged from 6.3 to 6.8 over the 96-hr test period; when the concentration was 490 mg/l, the pH

TABLE II.—Analysis of Dilution Water

Constituent	Amount
Total solids (mg/l)	165
Specific conductivity (mhos)	232×10^{-6}
pH	8.0
Hardness (mg/l)	45
Alkalinity (mg/l)	37

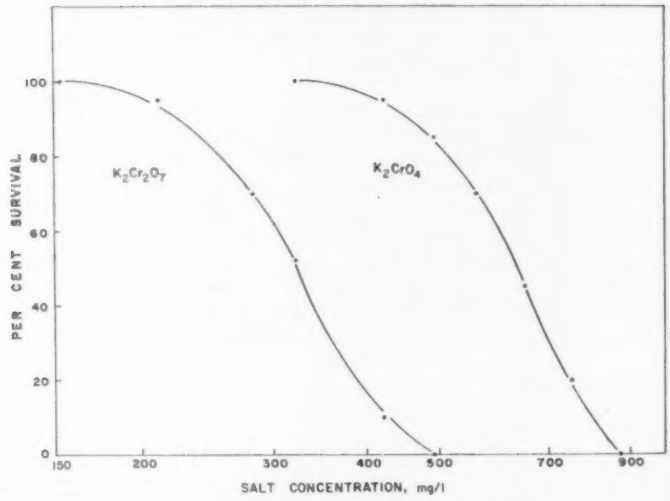

FIGURE 1.—Bluegill survival at various concentrations of chromium salts.

ranged from 6.0 to 6.2. With potassium chromate, the pH range was 7.5 to 8.5 when the concentration was 320 mg/l, and 7.8 to 8.5 when the concentration was 870 mg/l. With either salt, the pH tended to shift toward neutrality, and the rate of change was, in general, uniform over the 96-hr period. The observed shifting of the pH can be partially attributed to the very heavy secretion of mucous by the fish. Carpenter (26) has shown that the secretion of mucous was a reaction to chemical irritation, and, further, that this secretion tends to "detoxify" water by precipitating metal ions. The initial pH of the control bottles was always around 8.0, but it tended to decrease to as low as 7.3 over the 96-hr period. This "buffering" action by fish is well known to fish physiologists.

The toxicity response curves for both salts over a 96-hr exposure were typically sigmoid when the logarithm of the concentration was plotted against the per cent survival (Figures 1 and 2). When potassium dichromate was used (Figure 2), the 96-hr median tolerance limit was 113 mg/l Cr. With potassium chromate, the TL_m was 170 mg/l Cr.

For comparative purposes, the earlier results of Abegg (14) and Fromm and Schiffman (8) are pertinent. Abegg's estimate for the 24-hr TL_m for bluegills was about 300 mg/l; Fromm and Schiffman's estimate for bass was about 200 mg/l. According to data on mortality in the first 24 hr of tests not reported here, the authors' estimate of the 24-hr TL_m for bluegills in soft water would be about 175 mg/l Cr for potassium dichromate and 225 mg/l Cr for potassium chromate. The harder water used by Abegg apparently reduced mortality, but bass are apparently so much more sensitive to chromium than bluegills that they were not protected by the greater hardness of the dilution water employed by Fromm and Schiffman.

Discussion

Expressing the toxicity of hexavalent chromium salts in terms of milligrams per liter of the salt or even of chromium obscures the picture. The 96-hr response curves for K_2CrO_7 and

$K_2Cr_2O_7$ (Figures 1 and 2) are separate and distinct curves. Even when given on a basis of the chromium content, each curve gives a different 96-hr TL_m depending on the chromium salt used. It might be argued that a lower pH (6.0 to 6.8) makes dichromate salts more toxic to fish than chromate salts, but the whole story is told in terms of the ionization equilibria involved. Any aqueous solution of either a dichromate or monochromate salt will ionize according to the following expression (27):

$$2CrO_4^{=} + 2H^+ \rightleftharpoons 2HCrO_4^- \rightleftharpoons Cr_2O_7^{=} + H_2O$$

The hexavalent chromium ion, as such, does not exist in an aqueous solution of the salt. It can also be seen from the equilibrium expression that the hydrogen ion concentration affects the equilibrium between the chromate ($CrO_4^{=}$), hydrochromate ($HCrO_4^-$), and dichromate ($Cr_2O_7^{=}$) ions.

The ionic partition can be calculated if the molarity of the introduced salt and the ambient pH are known. New values for the equilibrium constants given by Neuss and Rieman (28) are:

$$\frac{[Cr_2O_7^{=}]}{[HCrO_4^-]^2} = 43.5 \quad \ldots\ldots (1)$$

and

$$\frac{[H^+][CrO_4^{=}]}{[HCrO_4^-]} = 3.20 \times 10^{-7} \quad \ldots (2)$$

The sum of the molar concentration of the three forms of chromium must equal the total molar concentration of chromium, thus:

$$[CrO_4^{=}] + [HCrO_4^-] + 2[Cr_2O_7^{=}] = [Cr] \quad \ldots (3)$$

This, of course, does not take into account the polychromate ions, but these are not of quantitative significance except under very acid conditions. These three expressions completely describe the ionic partition, and yield, upon combination, the following quadratic:

$$\frac{3.2 \times 10^{-7}}{[H^+]}[HCrO_4^-] + [HCrO_4^-] + 87[HCrO_4^-]^2 = [Cr] \quad \ldots (4)$$

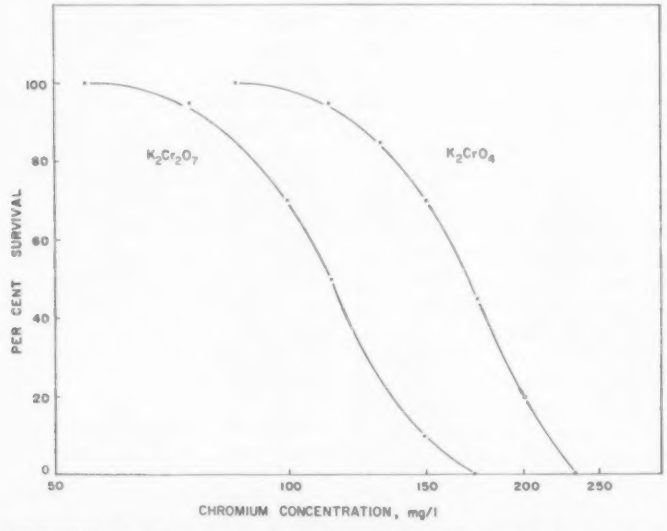

FIGURE 2.—Chromium toxicity of potassium dichromate and potassium chromate.

TABLE III.—Ionic Partition in Solutions of Potassium Dichromate and Potassium Chromate and 96-Hr Survival of Bluegills

Salt (mg/l)	Chromium (mg/l)	pH	Ionic Partition* (molarity × 10^6)				96-Hr Survival (%)
			Total Cr	$HCrO_4^-$	$CrO_4^=$	$Cr_2O_7^=$	
(*a*) Potassium Dichromate							
155	55	6.3–6.8	10.54	4.80	5.50	0.11	100
210	74	6.2–6.6	14.29	7.70	6.10	0.27	95
280	99	6.2–6.6	19.04	10.20	8.10	0.47	70
320	113	6.3–6.5	21.77	11.50	9.10	0.58	50
420	148	6.0–6.3	28.58	17.80	8.10	1.39	10
490	173	6.0–6.2	33.33	21.20	8.40	2.20	0
(*b*) Potassium Chromate							
320	86	8.5–7.5	16.50	0.9	15.7	0.01	100
420	113	8.7–7.6	21.65	1.1	20.2	0.01	95
490	131	8.8–7.7	25.25	0.8	24.2	0.01	85
560	150	8.5–7.7	28.87	0.9	26.8	0.01	70
650	174	—	33.47	—	—	—	45
750	210	8.7–7.6	38.65	1.7	37.7	0.02	20
870	233	8.5–7.8	44.85	1.3	42.9	0.02	0

* For purposes of calculating the partition of chromium into its various ionic forms, the midpoint of the pH range was used.

The equilibrium values given in Table III were calculated by using in Equation 4 the midpoint of the pH range for each test.

Ionic partition under the conditions of the test using potassium dichromate (Table III*a*) was from 46 to 64 per cent $HCrO_4^-$, from 52 to 22 per cent $CrO_4^=$, and from 1 to 7 per cent $Cr_2O_7^=$. In the tests using potassium chromate (Table III*b*), the partition was from 5 to 3 per cent $HCrO_4^-$, from 93 to 97 per cent $CrO_4^=$, and from 2 to 5 per cent $Cr_2O_7^=$. From the data it would seem that the hydrochromate ion is more toxic than the chromate ion. This is to be expected since monovalent ions are more readily absorbed than divalent. Relatively speaking, there are few dichromate ions present under the range of concentrations and pH involved here.

The addition of either dichromate or monochromate salt to a strongly buffered water would result in a partition poised by the acid-base buffer, but it is highly unlikely that a bio-assay could be conducted under these conditions because of the toxic effects (probably osmotic) of the buffering salts. Bluegills were found unable to tolerate known buffer systems more concentrated than 0.3 M (12), and this is less than the molar concentration required to maintain a constant pH after the addition of hexavalent chromium salts in the toxic range.

Conclusions

The 96-hr TL_m for bluegills in soft water is of the order of 110 mg/l Cr where hexavalent chromium enters the system as dichromate (or along with acidity equivalent to the dichromate), and the 96-hr TL_m where chromium enters soft water as chromate is about 170 mg/l Cr. The difference in the two values may be explained this way: at the lower half of the physiological pH range, the greatest part of the hexavalent chromium in the system is in the form of the univalent hydrochromate ion which is probably much

more readily absorbed than the divalent chromate ion. Only a very small part of the total hexavalent chromium present is in the form of dichromate, even at the lower end of the physiological pH range. Alkalinity and concomitant hardness significantly reduce the toxicity of solutions containing hexavalent chromium.

The 24-hr TL_m for bluegills in soft water is between 175 and 225 mg/l Cr. This index is also significantly affected by alkalinity and hardness, of course.

It is important to consider the reserve of alkalinity of the receiving body of water as well as the dilution involved in the disposal of wastes containing hexavalent chromium.

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MEETINGS OF INTEREST

Aug. 22–27	**Seventh International Conference on Coastal Engineering,** The Kurhaus at Scheveningen, The Hague, Netherlands. Prof. J. W. Johnson, University of California, Building 159, Richmond 4, Calif.
Aug. 29–31	**Symposium on Water Quality Data Collection and Utilization,** Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio.
Sept. 11–16	**American Chemical Society,** New York, N. Y. American Chemical Society, 1155 16th St., N. W., Washington 6, D. C.
Sept. 20–23	**United States Civil Defense Council,** Lexington Hotel, Minneapolis, Minn. Elliott R. Jackson, Municipal Auditorium, Atlanta, Ga.
Oct. 2–9	**Inter-American Association of Sanitary Engineering,** Hotel Carrasco, Montevideo, Uruguay. F. W. Montanari, 414 Walnut St., Room 302, Cincinnati 2, Ohio.
Oct. 10–14	**American Society of Civil Engineers,** Statler Hotel, Boston, Mass. W. H. Wisely, ASCE, 33 West 39th St., New York 18.
Oct. 18–21	**First Effluent and Water Treatment Convention,** The Seymour Hall, London, W. 1, England. Thunderbird Enterprises Ltd., 140 Cromwell Rd., London, S. W. 7, England.
Oct. 31–Nov. 4	**American Public Health Association,** San Francisco, Calif. Berwyn F. Mattison, M.D., Executive Director, 1790 Broadway, New York 19.
Dec. 12–14	**National Conference on Problems and Progress in Water Pollution Control,** Sheraton-Park Hotel, Washington, D. C. U. S. Public Health Service, Washington, D. C.

THE OPERATOR'S CORNER

PACKAGE AND SUBDIVISION SEWAGE TREATMENT PLANTS *

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In March 1958, the Conference of Municipal Public Health Engineers released the brochure "Coping with Suburban Sewage Disposal Problems" (1). This publication stressed the need for information which would permit performance levels of package sewage treatment plants to be predicted.

To partially satisfy this need, the Florida State Board of Health, the University of Florida, and the U. S. Public Health Service collaborated in a study of subdivision and "package" sewage treatment plants in Florida during the period from June 15 to Sept. 15, 1958.

Procedures

The studies began with a review of the State Board of Health records and preparation of a tentative list of the plants to be visited. It was recognized that comparisons with traditional-type plants would be necessary and that the ideal situation would be one in which at least three plants of each type could be studied, including an overloaded plant, an underloaded plant, and one loaded at about design capacity. It was further recognized that the range of flows under such circumstances should be relatively narrow; it was initially planned to limit the study to plants receiving sewage flows under 100,000 gpd.

It soon became apparent that the desired objectives were almost Utopian. Of three Infilco Aero-Accelator installations approved by the State, only one had been built. Of six Yeoman's Cavitators approved, only two were in operation; the remaining four had not been constructed. For similar reasons, only two out of seven Chicago Pump RatedAeration plants were available for study and only one out of seven Hays-Griffith plants. A single Walker Process plant was not even approved until about two weeks before the studies started. Conversely, there were dozens of plants of trickling filter design readily available for study, but a number of these were eliminated because of the absence of accurate flow measuring devices, electric power meters, and other facilities. As will be noted later, several of the aeration plants also were woefully lacking in some of the facilities needed for a proper evaluation of their operation, but there was little or no choice in their selection.

After the first eliminations, the list of potential installations was reduced to 34 plants in nine counties. Since

* Presented at the Annual Meeting of the American Public Health Association; Atlantic City, N. J.; Oct. 19–23, 1959.

most of these were of the trickling filter design, and all of the package-type aeration plants were in three counties, it was decided to concentrate in those three counties. They included Duval County in north Florida, Dade on the lower east coast, and Pinellas which is centrally located on the west coast. Specifically, six plants in Duval County, four in Dade, and four in Pinellas were studied.

The types of plants included in the survey are shown in Table I.

All of the plants received mostly sanitary sewage, except for one which was treating milk wastes. Plants serving the shopping centers included a considerable amount of kitchen wastes from restaurants, but no laundry wastes. Secondary treatment, including secondary settling, was provided at all of the plants except for the single primary treatment plant studied.

Results and Discussion

Data summarizing operations are given in Tables II, III, IV, and V.

TABLE I.—Plants Studied

Type of Plant	No.
Imhoff tank & std.-rate filter	2
Primary tank & H-R filter	1
Spiragester & H-R filter	3
Spiragester & std.-rate filter	1
Spiragester	1
Aero-Accelator	1
Cavitator	2
Hays-Griffith	1
RatedAeration	2
Total	14

These tables include information on BOD, solids, grease, pH, nitrogen, costs, power consumption, flows, and populations.

Duval County

As originally planned, it was intended that as much analytical work as possible be performed in local laboratories near the plants visited. The exceptions were field tests for settleable solids, pH, residual chlorine, and dissolved oxygen. This plan worked fairly well in Duval County. For most of the

TABLE II.—Loading and Performance of Sewage Treatment Plants

Plant No.	Type of Service	Flow (gpd)	SS			BOD		
			Infl. (mg/l)	Effl. (mg/l)	Red. (%)	Infl. (mg/l)	Effl. (mg/l)	Red. (%)
	(*a*) Trickling Filter Plants							
1	Subdivision	123,700	71	74	0	71	13	82
2	Subdivision	198,500	117	40	66	148	15	90
3	Office building	23,000	150	22	85	93	10	89
4	Subdivision	88,350	57	22	61	64	8	88
5	Shopping center	—	133	16	88	225	9	96
6	Shopping center	57,200	243	46	81	527	89	84
7	Subdivision	43,000	212	37	82	155	38	76
8*	Municipality	42,600	134	59	56	152	68	55
	(*b*) Aeration Plants							
9	Subdivision	78,840	75	17	77	105	14	87
10	Shopping center	16,000	79	19	76	170	26	85
11	Motel	21,550	269	34	87	136	45	67
12	Motel	—	174	58	67	315	104	67
13	Electric mfg.	75,400	107	16	85	95	1	99
14	Dairy	41,000	79	102	0	371	84	77

* Primary treatment only.

TABLE III.—Power Consumption, Flow, and Cost Data

Plant No.	Flow (gpd)		Power (kwhr/day)	Cost of Plant ($)		Design Pop.	Per Capita Cost ($)
	Design	Actual		Est.	Actual		
			(*a*) Trickling Filter Plants				
1	90,000	123,700	595	43,500	—	900	—
2	245,000	198,500	591	69,000	—	2,450	—
3	12,850*	23,000	—	24,600	—	340	—
4	192,500	88,350	127	42,000	85,000	1,925	44
5	80,000	—	—	35,000	—	1,600	—
6	56,000	57,200	—	35,000	—	1,120	—
7	120,000	43,000	76	60,000	—	1,200	—
8†	100,000	42,600	28	34,000	42,190	1,000	—
			(*b*) Aeration Plants				
9	100,000	78,840‡	100	34,000	60,000	1,000	60
10	12,000	16,000	72	27,700	67,700	240	280
11	44,000	21,550	—	35,000	65,000	440	150
12	19,500	—	—	20,000	45,000	200	225
13	32,700	75,400	—	65,000	71,200	490	145
14	31,000§	41,000	320	35,000	53,673	1,060	50

* In 9 hr. † Primary treatment only. ‡ Estimated. § In 8 hr.

TABLE IV.—Solids, pH, and Grease Data

Plant No.	Solids						pH		Grease (mg/l)	
	Settleable (ml/l)		Total (mg/l)		Vol. (mg/l)					
	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.	Infl.	Effl.
				(*a*) Trickling Filter Plants						
1	9.7	0.1	470	520	210	250	7.4	7.3	24.8	19.6
2	4.5	0.1	503	475	213	185	7.1	7.4	22.6	11.0
3	7.5	0	810	710	400	300	7.7	7.2	15.2	17.6
4	1.5	0	450	420	180	300	7.1	7.3	32.8	14.8
5	tr.	tr.	940	830	470	240	7.2	7.6	—	—
6	19	0.4	1,143	501	528	142	6.6	7.2	58.9	21.1
7	9.0	0.1	874	548	384	219	7.6	7.9	51.8	18.8
8*	2.8	0.1	765	636	293	222	7.8	7.3	40.2	28.2
				(*b*) Aeration Plants						
9	4.6	0.3	450	215	180	60	7.2	7.4	23.4	16.6
10	3.8	0.2	835	672	341	135	7.5	7.3	47.2	37.1
11	12.3	—	700	515	288	172	7.5	7.4	60.1	14.8
12	16.0	0.1	776	558	321	189	7.1	6.8	43.4	19.1
13	9.5	0.1	607	503	275	223	7.7	7.6	19.2	10.4
14	0.1	5.9	786	644	527	289	8.4	7.6	90.4	30.1

* Primary treatment only.

TABLE V.—Nitrogen Data

Plant No.	Total Organic Nitrogen (mg/l)					Nitrite Nitrogen (mg/l)					Nitrate Nitrogen (mg/l)				
	Infl.	Primary Effl.	Oxidation Unit Effl.	Secondary Effl.	Final Effl.	Infl.	Primary Effl.	Oxidation Unit Effl.	Secondary Effl.	Final Effl.	Infl.	Primary Effl.	Oxidation Unit Effl.	Secondary Effl.	Final Effl.
(a) Trickling Filter Plants															
1	21.3	20.1	14.7	13.0	11.9	0	0	0	0	0	0.54	0.38	0.34	0.38	1.20
2	21.8	21.4	18.1	17.1	15.9	0	0	0	0	0	0.34	0.34	0.33	0.33	1.12
3	47.5	30.4	16.5	15.1	—	0	0	0	0	—	0.84	0.40	0.28	1.20	—
4	0.84	9.38	4.76	4.2	3.8	0	0	0	0	0	0.34	0.32	0.30	0.28	0.11
5	—	13.0	8.0	6.7	—	0	0	0	0	—	0.76	0.38	0.30	1.10	—
6	39.4	29.1	25.2	—	21.0	25.0	0	0	—	0	0.57	0.50	0.30	—	0.29
7	40.9	33.3	26.9	—	23.9	0.19	0.04	0.80	—	0.80	0.11	0.12	1.00	—	0.28
8*	37.0	32.2	—	—	—	8.7	0	—	—	—	0	0	—	—	—
(b) Aeration Plants															
9	23.2	22.2	16.3	10.7	10.5	0	0	0	0	15	0.47	0.38	0.35	0.28	1.11
10	33.0	—	381	—	10.5	1.7	—	0	—	0	1.13	—	0.71	—	0.29
11	41.4	35.2	—	—	27.5	0	0	—	—	0	0.33	0.28	—	—	0.26
12	36.9	—	223	—	33.2	6.3	—	0	—	0	2.3	—	0.43	—	0.21
13	26.9	—	128	—	4.2	0	—	1.5	—	0.16	0	—	10.1	—	0.25
14	17.6	—	65.0	—	9.9	12.6	—	0	—	0	0.23	—	0	—	0

* Primary treatment only.

plants in that county, composite, 24-hr samples were collected and a chemist employed by the State Board of Health ran determinations for pH, settleable solids, and BOD. Aliquots of preserved portions of these samples were brought to the University Sanitary Engineering Research Laboratory for nitrogen, grease, and solids determinations. The composite, proportional samples were made from individual samples collected generally at 2-hr intervals. For grease determinations, 250-ml composite samples were preserved with 10 ml of chloroform; for nitrogen balance, 1-qt composite samples were preserved with 5 ml of sulfuric acid.

At the start, an attempt was made to sample two plants at one time using one of two students on separate 13- to 14-hr day and night shifts. Of the plants selected for sampling on a given day, the one with the best laboratory facilities was used as "headquarters" and the field testing equipment and refrigerated samples were kept there. Unfortunately, the schedule as outlined was too difficult to follow and had to be abandoned.

It was observed that the 24-hr composite samples were unusually weak because the late evening and early morning samples consisted largely of ground-water infiltration. It was concluded, therefore, that the 24-hr samples did not yield the best information, and that results on daytime samples would be more significant. Since sewage treatment plants should be designed to operate effectively under the worst conditions, it was decided to collect samples from the plants in Dade and Pinellas Counties only during daytime hours.

Dade County

In Dade County, the schedules and procedures for sampling and field testing progressed more smoothly. Here, each of the two students remained at one plant for an entire day, usually from about 6 AM to 6 PM, and two plants were sampled each day as before. Settleable solids, pH, and BOD determinations were made in the lab-

oratory of the city of Coral Gables sewage treatment plant. Because of the distance from Gainesville to Miami (360 miles), the limited laboratory equipment and facilities available, and the difficulty of preserving samples for some of the solids determinations, an effort was made to facilitate the laboratory work by preparing Gooch crucibles in advance. The crucibles and asbestos fiber mats were ignited and weighed in Gainesville and carried with the rest of the equipment to Miami. The samples were filtered and the crucibles dried in Miami and brought back to Gainesville for reweighing. Although precautions were taken to handle and transport the samples as carefully as possible, some of the results were invalid because there was enough jarring to shake the mats and disturb the weights. Consequently, all of the suspended solids results on samples from Dade County were rejected and a special one-day trip to Miami was made to collect grab samples for suspended solids and other determinations. Results of the BOD determinations on the composite samples were also questionable and deleted from the report.

Pinellas County

As a result of the experiences in Dade and Duval Counties, it was decided that except for the usual field tests, all of the analytical work on samples from Pinellas County would be done in Gainesville. The sampling schedule was arranged so that freshly composited daytime samples could be shipped to Gainesville either by air parcel post or air freight. The refrigerated samples were taken to the airport shortly before plane departures and the planes were met at Gainesville by a student technician; thus, analytical work was started within about 2 hr after plane departure. The samples were shipped in sectionalized wooden boxes. The jars containing the refrigerated samples were filled completely at the airport just a few minutes before shipment and they were still cool when they arrived at the laboratory, despite hot weather.

The procedure as described went off without a hitch and the analytical results are considered as reliable as any which might ordinarily have been obtained using a mobile laboratory.

Any study covering only 14 plants during a three-month period cannot be expected to be definitive. Still, a number of valid conclusions would have been apparent even without the study, and others are indicated by past experience. To differentiate between conclusions based on data collected during the study and opinions formed from observations during the plant studies, the latter are included under a separate heading, "Miscellaneous Observations."

Conclusions

1. Some of the subdivision and package sewage treatment plants visited were producing excellent results; others were not.

2. Where satisfactory results were being obtained with the package plants, the quality of operation was also satisfactory.

3. In some cases, reasonably satisfactory results were being obtained at trickling filter plants which did not have good operation. For comparable results, the trickling filter plants required less attention than the aeration plants.

Miscellaneous Observations

1. Health authorities should not approve the installation of aeration-type package plants unless satisfactory maintenance and operation can be assured.

2. Manufacturers of package plants which include mechanical-aeration devices or compressors or other complicated equipment should acknowledge in their advertising that satisfactory

maintenance and operation are essential.

3. All manufacturers of package plants should provide either an adequate service organization, or have readily available field engineers or technicians who may advise and assist where troubles develop. Manufacturers and engineers should not expect state health departments to outlaw private septic tank installations in subdivisions unless full cooperation is given in obtaining satisfactory maintenance and operation.

4. Except in unusual circumstances, all plants of every type should be provided with convenient and accessible flow measuring devices, including a totalizing meter or the equivalent. Most plants also should be provided with electric power meters, so that adequate cost or performance data can be obtained.

5. In general, plants which were not equipped with adequate laboratory and sanitary facilities were not operated properly. Minimum sanitary facilities should include a toilet, wash basin, and shower.

Minimum laboratory facilities even in the simplest plants should generally include the following: a sink with running water, adequate work space, pH kit, Imhoff cones, thermometers, cylinders, flasks, beakers, bottles, pipettes, burettes, and other glassware as needed. For larger plants, and those with secondary treatment, additional laboratory facilities should be provided.

One of the student assistants summed it up this way. "Lack of laboratory facilities greatly hinders the operator. There is always a tendency to leave undone anything which seems inconvenient or difficult; also, where the operator has many other duties the time element may become important. Convenient laboratory facilities will greatly reduce the tendency to overlook routine lab work."

6. The designing engineer should be considerate of the person who will operate the plant. If more designing engineers had some operating experience, there would be fewer plants without steps and sampling facilities. Further, in Florida there are some who demonstrate something less than passable competency when it comes to the design of small plants.

7. Some of the monthly plant operating reports on file with the State were excellent. Others were grossly inaccurate. This points up the need for more technical services from state and local health departments. Plants should be visited more frequently and the operators given more training.

8. A station wagon was found very useful in the studies undertaken. A sedan did not have enough room to transport necessary equipment and containers, and a carry-all was too rough.

9. From Table III, it will be noted that estimated costs were available for all of the plants included in the survey, but actual costs were available for only 8 of the 14. It may be noted also that the actual costs exceeded the estimated costs by an average of approximately 67 per cent. A reason given for this was that actual costs are frequently used for income tax purposes, whereas estimated costs are used by local tax assessors. The explanation may have limited validity, but it is an example of one of the economic factors encountered by subdividers. Local taxes have been cited as one of the reasons why sometimes there is resistance to the construction of subdivision plants.

10. The following quotations from the report of the National Research Council on "Individual Household Aerobic Sewage Treatment Systems" (2) are believed almost equally applicable to aerobic package or community treatment plants.

(*a*) Mechanical Components . . . Emphasis should be placed on simplicity of design so far as is consistent with the

required characteristics and on ease of repair and replacement. The mechanical components [should] be readily accessible for inspection and preventive maintenance.

(*b*) Maintenance . . . The major components of these systems . . . should be covered by manufacturers' guarantee and/or replacement policy. These components should be expected to have a service life of at least five years and preferably ten years.

(*c*) . . . A factor that should be weighed in the decision [or selection] is the availability and adequacy of the maintenance that can be provided by the dealer.

11. "It is highly desirable to provide a buffer strip of at least 500–750 ft between the plant and the nearest housing to prevent odor complaints. Greater isolation should be provided if possible" (3). Enclosed plants offer an answer when the suggested distances cannot be obtained.

12. Among the safety hazards at some of the plants were:

(*a*) No hand railings around tanks;
(*b*) Walkways too narrow or entirely lacking;
(*c*) Uncovered channels, flumes, and influent structures; and
(*d*) Inadequate lighting for night work.

13. All of the indoor package plants had odor problems. The odors were most objectionable near the aeration units. ("Indoor" package plants are not to be confused with "enclosed" plants referred to under Item 11, and which are being found very successful in Florida. Enclosed plants are those within separate plant enclosures only; indoor plants are those in basements or constructed as part of a larger building.)

14. Under the present circumstances in Florida, it is believed that a trickling filter plant of conventional design is still to be preferred for most subdivisions and small communities.

15. While awaiting further proof on the efficacy of the more complicated of the aeration-type package plants, the desired end may be accomplished in some instances through stage construction of plants of proved designs (4).

16. In general, the results of samples composited during daytime hours are more significant than the results of 24-hr composites in evaluating the performance of plants serving subdivisions.

17. Filter flies caused trouble at plants where control measures were not in force. This applied to high-rate as well as standard-rate filters. During summer conditions in Florida, the control measures (flooding, prechlorination, or insecticide use) were needed every week or 10 days. Two operators stated that the time interval could be increased to a month or six weeks during the winter.

18. Analytical work performed by the operators at plants equipped with laboratory facilities was generally more reliable than the results of analyses of grab samples as reported by part-time chemists. The latter indicated performances better than could be verified during the studies herein reported.

19. Equipment such as air compressors generally should be furnished in duplicate.

20. Corrosion problems have been encountered at plants having steel tanks. The corrosion is most pronounced at the water line, but can be controlled with proper maintenance.

21. Complaints due to noise from air compressors are sometimes experienced at plants located near housing developments. The disturbances occur during late evening or early morning hours when background noises are at a minimum. In one instance it was reported that a nearby resident cut off a compressor when it interfered with his sleep. This resulted in septic conditions in the plant by the time the operator returned.

Recommendations

It is recommended that further studies be made on cost data, design criteria, and performance or operating efficiencies of subdivision and package sewage treatment plants. It is recognized that package plants are here to stay, and it is hoped and believed that many improvements will be made in them within the next few years.

It is believed that an unofficial plan or policy as adopted in Florida should have a salutary effect. This plan is to conditionally approve up to 10 installations of different types of package plants with the view of conducting such studies or research as may be necessary to determine which of the various types may yield satisfactory results. It is expected that types of plants which do not perform satisfactorily will be eliminated from further consideration. This should be accepted as a real challenge by manufacturers, and it should be welcomed by those who have good products and render good service.

Acknowledgments

The studies herein described were facilitated through the cooperation of a number of people. Among them were Mr. W. W. Towne, Mr. David B. Lee, and Prof. F. W. Gilcreas. In addition thanks go to: Messrs. Hugh W. Hodgden, Ralph Baker, Glenn C. Bradley, Charles E. Cook, Vincent D. Patton, and Nick Mastro, of the Bureau of Sanitary Engineering, State Board of Health; Messrs. R. L. Quick and James Spade, Dade County Health Department; Mr. W. C. Tims and Mrs. Pat Robinson, city of Coral Gables Sewage Treatment Plant; Mr. William E. Dunn, Pinellas County Health Department; Messrs. John E. Hagan, III, Larry P. Robinson, and Robert Connelly, student assistants; and many of the designing engineers, owners, officers, and operators of the plants visited.

The State Board of Health furnished a junior engineer to assist in the collection of samples and data from selected treatment plants, plus a carryall for the transportation of samples and equipment, and a chemist for the ordinary analytical determinations on samples collected in Duval County. The Public Health Service provided for the full-time service of a CO-STEP * student, the part-time service of a laboratory aide, and the part-time services of experienced chemists doing the more complicated analytical work.

All of the work was performed under the aegis of Mr. David B. Lee, Director of the Bureau of Sanitary Engineering, Florida State Board of Health. Prof. F. W. Gilcreas supervised most of the analytical work.

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* Commissioned Officer–Student Training Extern Program.

OPERATION OF THRUWAY TREATMENT PLANTS

By Irwin P. Sander

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To serve the many patrons using its 553 miles of superhighway, the New York State Thruway Authority has provided 29 service areas. Twenty-seven of these areas are tributary to 24 Authority-operated sewage treatment plants. The other two areas are connected to municipally operated plants.

During the summer of 1959, a survey was made of four of the Authority's plants to determine the efficiency of operation. The laboratory work was done by the New York Department of Health in Albany. The facilities available at each station are shown in Table I.

As the variation in traffic on the different days of the week was known, it was decided to test the plants over the week end when they would be getting the heaviest load. Originally, the four plants were to be sampled from 8 AM Thursday to 8 AM Monday, but because of circumstances which could not be foreseen when the program was set up, the last station was sampled only from Thursday to Sunday.

Sampling Procedures

Samples of raw sewage, primary effluent, and final effluent were collected and composited according to flow. The method of obtaining the flow is believed to be unique: A bubbler-tube arrangement was used to measure the head over a 90-deg V-notch weir. The pressure necessary to force a bubble out of the tube bottom is directly proportional to the head on the weir. This pressure was then measured and recorded on a recorder. Figure 1 shows the bubbler tube; Figure 2 shows the recorder and the cylinder of carbon dioxide which supplied the gas to bubble through the system. The CO_2 was first passed through a pressure-reducing valve and then through a constant air flow meter so that it was fed at a constant rate and not dependent on the pressure. The pressure-sensing bellows had a rating of 0 to 10 in. of water. The head was recorded on a chart that made one revolution in 24 hr so that a permanent record of the flow was obtained. After collecting the samples, the collector would read the chart to see what the head over the weir had been at the time of collection. Then, by use of previously prepared tables, the flow in gpm was obtained. This flow was then used to determine the amount of sample to be placed in the composite bottle.

TABLE I.—Types of Service Areas

Station	Type*
Sloatsburg-Ramapo	AA & E
Malden	A
Pattersonville	A
Guilderland	C

* AA—Cafeteria, snack bar, gas station; A—Restaurant, coffee shop, snack bar, gas station; C—Snack bar, gas station; E—Gas station.

The head-measuring equipment was very satisfactory because of its portability and the ease with which it could be set up. All of the plants on the Thruway have 90-deg V-notch weirs in place so that setting of the weir presented no problem. The "zeroing" of the bubbler tube to the bottom of the V-notch was done in a matter of minutes using an ordinary line level. For future work it is planned to build a V-notch weir with the bubbler tube permanently zeroed in.

In addition to the compositing of the samples, the collectors ran settleable solids determinations every two hours. The samples were iced and the col-

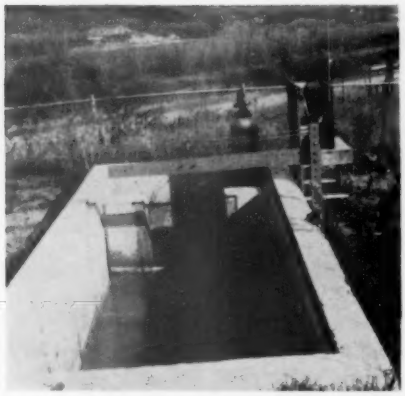

FIGURE 1.—V-notch weir and bubbler tube.

lectors brought the 12-hr composites into the laboratory at Albany for pH, grease, and BOD analyses.

Descriptions of Plants Tested

Of the four plants tested, Sloatsburg is a two-stage, high-rate trickling filter plant; Pattersonville is a primary plant; Guilderland is a single-stage, high-rate trickling filter plant; and Malden, a high-rate trickling plant followed by open sand filters. To compare the results of the trickling filter treatment, the effluent of the Malden plant was taken from the final clarifier rather than the sand filter. All plants are provided with comminuting devices. Pre- and post-chlorination are possible at all plants, but pre-chlorination was practiced only at Malden during the testing. No samples of the final chlorinated effluent were collected, so the results of the final effluent would be improved by the final chlorination.

Both circular and rectangular clarifiers were included in the testing program. Sloatsburg and Guilderland have circular clarifiers while Malden and Pattersonville have rectangular ones. Direct recirculation of the filter effluent is employed at Sloatsburg and Guilderland; at Malden the filter effluent is discharged to the final clarifier which has a take-off to the wet wells at the influent end of the clarifier.

Sewage Flow

Table II is a comparison of the maximum daily flows with the design flows. An inspection of this table would, at first glance, make it appear that Malden was approaching its design figure while the flow at Pattersonville was exceeding it. However, all units were designed on the 16-hr flow rather than the 24-hr basis. Using this as a basis of comparison, it can be seen that no plant is overloaded, and the plant most closely approaching the design flow is Pattersonville, which, at maximum, was 86 per cent of design load.

It must be emphasized that the actual flows in this table are maximum flows found during the test periods. They are believed to be representative of the flows that may be found during a summer week end with the exception of the flows at Sloatsburg. Sloatsburg was tested during a period when flows are usually at a summer low.

Figures 3, 4, and 5 show typical flow patterns for Pattersonville, Guilderland, and Malden. The graphs indicate quite vividly the differences and similarities that exist among the different

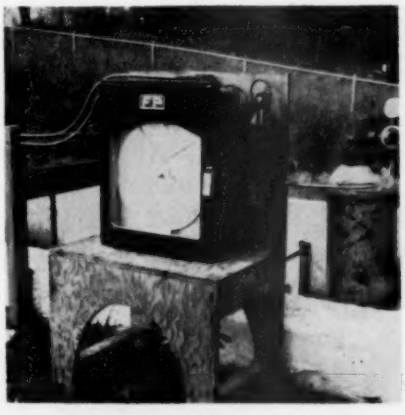

FIGURE 2.—Pressure recorder.

TABLE II.—Comparison of Design and Actual Flows and Recirculation Factors

Plant	Flow (gpd)				Recirculation (%)		
	24-Hr Rate		16-Hr Rate		Design	Actual	
	Design	Actual*	Design	Actual*		Low	High
Sloatsburg	130,000	43,500	200,000	59,500	200	900	2,100
Malden	54,000	49,000	80,000	59,000	200	330	400
Guilderland	54,000	10,800	80,000	11,700	200	2,200	2,900
Pattersonville	54,000	63,000	80,000	69,100	—	—	—

* Maximums during test period.

stations. Guilderland being a *C* station does not have air conditioning, dishwashing facilities, or extensive refrigeration facilities as are found in the other two stations.. The base flow at Guilderland, midnight to 6 AM, is probably due to the bleedoff from two water-cooled refrigeration compressors, while the base flow at the other two locations is contributed by dishwashing, bleedoff from air-conditioning cooling towers, and many water-cooled refrigeration compressors. On the Pattersonville graph, Figure 3, many sudden peaks may be noted. These peaks can be found almost every day, and investigation revealed they coincided with bus stops. The peaks must be taken into account when designing facilities for any type of turnpike installation. If the facility is not connected to a municipal supply, ample storage must be provided to tide the station over these peaks.

For the Thursday-to-Sunday flow at the Sloatsburg service area, the average flow increased each succeeding day, with the high Sunday flow extending over the entire day. Each day the base night flow dropped quite low with

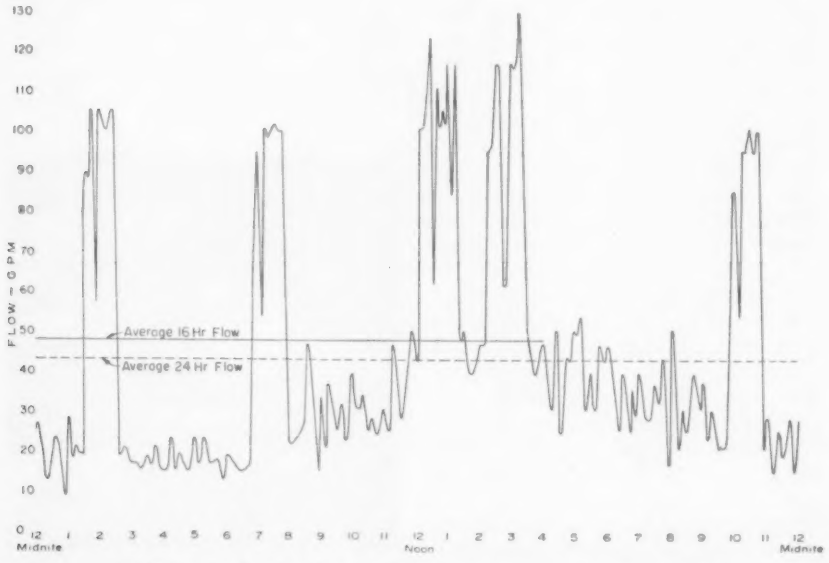

FIGURE 3.—Sewage flow at Pattersonville area on Aug. 9, 1959.

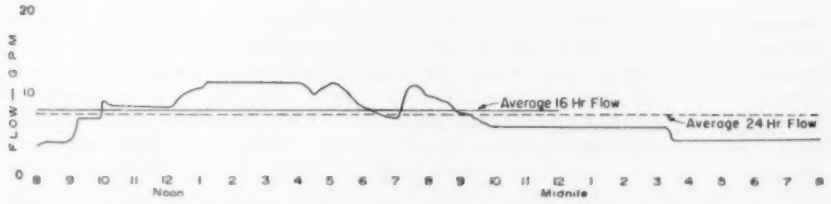

FIGURE 4.—Sewage flow at Guilderland area on Aug. 16–17, 1959.

the exception of Saturday morning. This is due to the crowds going to the Catskill Mountain resorts on the week end. The base flow at Sloatsburg is much less than the base flows at Malden and Pattersonville even though Sloatsburg is a much larger station. The reason is that at Sloatsburg a different type of air conditioning and refrigeration system is employed and not as much water is required.

Because actual flows never approached the design flows, the recirculation at Guilderland, Malden, and Sloatsburg far exceeded the design figures. In Table II is a comparison of the design, low, and high percentages of recirculation. The high percentage of recirculation probably accounts for the excellent treatment results.

Analytical Results

At the three plants which have secondary treatment, the samples were collected every half hour. At Pattersonville, the lone primary plant, samples were taken every 15 min. Table III contains the results of the BOD and grease analyses.

Guilderland

The pH of the influent sewage varied from 7.0 to 9.6 and the effluent shows approximately the same variation. The pH was taken by the sample collectors, but halfway through the sampling period the batteries on the meter failed. It was then decided to measure the pH of the composite only; this was done with the samples at Sloatsburg and Malden. Because there are no

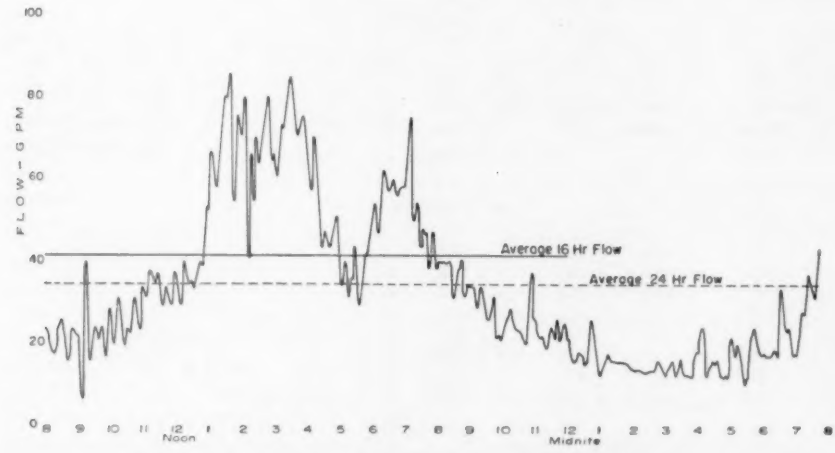

FIGURE 5.—Sewage flow at Malden area on Aug. 28–29, 1959.

restaurant wastes at Guilderland, the influent sewage had BOD and grease concentrations within what might be considered the normal range for domestic sewage. The primary tank showed average reductions of 36 per

TABLE III.—Thruway Treatment Plant Performance

Date (Aug. 1959)	Time*	Sewage Strength (mg/l)						Removal (%)			
		Infl.		Primary Effl.		Secondary Effl.		Primary		Over-all	
		BOD	Grease	BOD	Grease	BOD	Grease	BOD	Grease	BOD	Grease
					(*a*) Guilderland						
13	day	273	60	148	29	9.3	3.3	46	52	97	95
13–14	night	255	35	174	27	6.3	3.0	32	23	98	87
14	day	156	61	102	27	6.9	1.1	35	56	96	97
14–15	night	240	49	123	24	3.0	2.1	49	50	99	92
15	day	141	26	111	19	3.3	3.5	21	27	98	91
15–16	night	225	36	138	25	2.1	3.7	39	31	99	90
16	day	186	27	128	22	7.2	1.2	31	20	96	96
16–17	night	225	33	162	25	6.6	3.3	28	25	97	90
Avg	—	213	41	136	24	5.6	2.7	36	42	98	93
					(*b*) Sloatsburg—Ramapo						
20	day	480	161	288	99	8.7	6.6	40	39	98	96
20–21	night	504	240	252	106	8.1	4.3	50	56	98	98
21	day	576	111	312	70	7.8	1.4	46	37	98	88
21–22	night	504	91	384	60	13.4	8.8	31	34	97	90
22	day	372	95	255	70	12.6	19	31	27	97	80
22–23	night	492	146	258	49	15.6	12	48	67	97	92
23	day	348	98	234	49	14.4	4.9	33	50	96	95
23–24	night	504	153	276	49	27.9	2.8	45	68	95	98
Avg	—	473	137	281	69	13.5	9.5	41	49	97	93
					(*c*) Malden						
27	day	564	309	201	80	58	18	65	74	90	94
28	day	578	188	237	70	65	8	59	63	89	96
29	day	444	143	267	75	36	10	40	47	92	93
29–30	night	324	101	300	92	28	4	7	9	92	96
Avg	—	478	185	251	79	48	10	43	48	91	94
					(*d*) Pattersonville						
6	day	612	151	468	126	—	—	23	17	—	—
6–7	night	285	100	255	89	—	—	12	12	—	—
7	day	446	129	432	98	—	—	3	23	—	—
7–8	night	336	60	360	84	—	—	—	—	—	—
8	day	408	123	432	92	—	—	—	25	—	—
8–9	night	276	160	264	72	—	—	4	55	—	—
9	day	372	97	324	88	—	—	4	9	—	—
9–10	night	237	135	273	99	—	—	—	27	—	—
Avg	—	384	119	351	94	—	—	9	21	—	—

* Daytime sampling was normally from 8 AM to 8 PM; nighttime, from 8 PM to 8 AM.

cent for BOD and 42 per cent for grease, while the secondary process, including the final tank, gave excellent removals averaging 98 per cent for BOD and 93 per cent for grease. These far exceed the normal removals for this type of plant. However, it must be remembered that the recirculated flow far exceeded what is normally used in municipal design.

Sloatsburg

At this location because of the huge cafeteria at Sloatsburg and the rest rooms at Ramapo, the sewage is much stronger than a normal domestic waste. The BOD varied from a low of 372 mg/l to a high of 576, averaging 473 mg/l. The grease content ranged from a low of 91 mg/l to a high of 240, averaging 137 mg/l. The primary tank was operating very efficiently, giving an average BOD removal of 41 per cent and average grease removal of 49 per cent. The two trickling filters in series together with the final settling tank gave excellent results. The average BOD concentration in the final effluent was only 13.5 mg/l. The grease in the effluent from the final tank was only 9.5 mg/l. Here again the results of the extremely high (900 to 2,100 per cent for each stage) percentage of recirculation probably accounts for the excellent treatment results. An even better over-all plant efficiency would have shown if the samples had been taken after final chlorination.

Malden

At Malden, the restaurant wastes make the sewage strong, the average influent BOD being 478 mg/l. The lowest BOD influent came during the Sunday-night–Monday-morning shift when traffic was lightest. It was during this period that the primary clarifier gave the poorest reductions, 7 per cent for BOD and 9 per cent for grease. The over-all plant reductions (not including the sand filters) were very good, 91 per cent for BOD and 94 per cent for grease. Chlorine in excess of 20 mg/l was fed into the sewage ahead of the primary settling tanks during the test periods. This amount of chlorine seemed to have an effect on the removal during the first two days.

Pattersonville

The sewage at Pattersonville is not as strong as the other two sewages which contain restaurant wastes, the BOD being almost 100 mg/l lower, averaging 384 mg/l. The efficiency in the primary tank at Pattersonville is very poor and no explanation can be given for the low removal of BOD.

As indicated previously, the sample collectors ran settleable solids determinations at the time of compositing the samples. However, in the final analysis, it was found that the results varied too much among the different collectors and they have not been reported.

Conclusions

1. None of the plants tested has reached its design hydraulic load.
2. At the secondary plants, the actual recirculation ratios are far in excess of the design ratios.
3. The sewage at locations where there are restaurants is very strong; at locations without restaurant facilities, a normal, domestic sewage is found.
4. Removals of BOD and grease in the secondary plants are excellent, far exceeding normal values with this type of plant.
5. Prechlorination with high dosages may have some merit with this type of sewage.

Acknowledgment

The writer wishes to thank Dr. Meredith Thompson, Director of the

Bureau of Environmental Sanitation of the New York Health Department, for the loan of three Junior Sanitary Engineers who did the sampling and to Mr. Wallace W. Sanderson, Assistant Director, Division of Laboratories and Research, who provided personnel to do the laboratory analysis.

PUBLIC LIABILITY AND TREATMENT PLANT SAFETY *

By C. G. Hammann and C. Y. Hitchcock, Jr.

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What is to follow is an account of an imaginary period at an imaginary facility designated the Center County Sewage Treatment Plant located at Notown, N. J. This plant is an element of a system administered by the Center County Sewer Commission and it is managed by Sam Seed, Executive Engineer.

One day early in the period in question, Sam arrived promptly at his usual starting time—10:00 AM. Unfolding the Notown News, he learned that an aspirant of the Thinking Man's Party had excoriated him in a campaign speech the previous evening for no other reason than that Sam's staff comprises, among others, his brother, his son, his father-in-law, two brothers-in-law, a second cousin once removed, and his wife's uncle.

Sam disgustedly heaved the paper in the waste basket and joined his staff in the lunch room where they were assembling for the morning coffee break. Over coffee and crumpets, he learned from the office manager that a Workmen's Compensation rating report had been received in the morning mail. The fact that the report made reference to a less than commendable accident incidence for the rating period was not news to Sam, of course. But it was quite a jolt to learn that the frequency and intensity of these accidents had resulted in a 22 per cent increase in insurance rates.

Having endured human misery when the accidents occurred, and having suffered the consequences of upset schedules and replacement problems following the accidents, Sam considered the news concerning a rate increase to be a crowning blow. Mixing metaphors, it also was a bitter pill to swallow because Sam had included in his previous budget requests funds with which to initiate a safety training program and to defray the cost of correcting certain hazardous conditions at the plant. Disallowance of Sam's requests had not only contributed to his current predicament, it also created the problem of how to stretch an already slender budget to meet the increased Workmen's Compensation premiums. At this point, Sam went home, took a triple dose of ulcer medicine, and went to bed.

Returning to work the following day, Sam had nothing to do but sit and gaze out the window meditating upon how he could meet the increased insurance premiums. Deep in reverie, he subconsciously observed a young boy approach the plant from a nearby residential area. As Sam watched, the boy sauntered onto the side wall of a drainage channel near the edge of the plant site, lost his balance, and fell

* Presented at the Annual Meeting of the New Jersey Sewage and Industrial Wastes Assn.; Atlantic City, N. J.; Mar. 30–Apr. 1, 1960.

in. Sam rushed to the scene and was greatly relieved to find that the channel was dry. Unfortunately, however, the boy had a fractured arm. Sam had the boy's parents notified, arranged for transportation to the accident ward, and subsequently learned that the boy would suffer no complications. Thinking the incident was closed, Sam's ulcer again began popping a short time later when he was informed that a damage suit had been instituted on the boy's behalf. Cited as grounds for damages—an attractive nuisance—to wit, an unfenced plant site.

The next few days were uneventful. Uneventful, that is, from the point of view of accidents involving personal injury. Fortunately, a few minor incidents occurred which kept Sam occupied. The sludge barge developed a leak and had to go to dry-dock for repairs which would require fifteen days. This wasn't too serious though because Sam had ample storage capacity for three days' sludge production. Similarly, notice was received that, due to a rail strike, a car of chlorine in transit would probably be delayed for about two weeks. However, Sam had sufficient chlorine for at least four days. These, and less aggravating things like burned bearings, broken shafts, ruptured piping, and a few other routine occurrences served to keep Sam from being idle and becoming morose.

One morning after this respite, Sam approached the plant with his customary promptness. In fact, he was early, the time being only 9:30 AM. His premature arrival was occasioned by the fact that he had to drop his wife downtown. Sam had to have one car himself that day, his son was using another, and he had loaned his third car to a friend.

In any event, as he turned into the administration building drive, Sam observed that a truck had struck a telephone pole. The truck was the property of a painting contractor who recently had been awarded a contract at the plant for the first time, and this was his first day on the job. During the night, a foaming problem had developed at the plant. Simultaneously, a brisk wind blew the foam in the direction of the drive where it deposited and formed a slippery coating. Unaware of this condition, the driver had applied his brakes and skidded into the pole with the result that:

1. The driver was injured.
2. The truck was damaged extensively.
3. Ladders and staging were demolished.
4. A considerable amount of paint was spilled in the area.
5. The telephone pole was completely sheared at the base and circuits were disrupted.
6. Sam had to abandon his car and walk the remaining hundred yards to his office.

After ascertaining that the truck driver would recover, Sam concerned himself with straightening out the mess. The truck and debris were removed and arrangements were made for restoration of telephone service. Sam then summoned the painting contractor to his office to arrange for prompt removal of the spilled paint because of an anticipated plant inspection by the Center County Wining and Dining Society.

When he appeared, the contractor was accompanied by his insurance adjuster and the insurance company attorney. Sam was delighted to learn that the contractor had full insurance coverage and that he would be fully reimbursed for all damages incident to the situation. His joy was short-lived, however, for he was informed by the attorney that the insurance company had had abundant experience in such matters, that it considered the Center County Sewer District clearly liable, that action would be instituted to recover from the District all dam-

ages paid to the Contractor, and that judgment or settlement would unequivocably be in favor of the insurance company.

For a considerable period following this incident Sam divided his time equally between his psychiatrist's couch and consideration of the effect of the accident upon his overly strained budget and his carefully guarded reserve fund.

Finally the day arrived when the delegation from the Center County Wining and Dining Society was to visit the plant. Sam had taken great pains to arrange an interesting and informative inspection by the group because he aspired to membership in the Society.

The delegation reached the plant on schedule and in enthusiastic spirits. Among the delegation were Attorney John Smith, an eminent legal authority, and Richard Jones, M.D., whose fortuitous presence was very significant as will be seen.

Sam conducted the group to the head works and explained the functions of screening and grit removal facilities. While milling around the grit chamber, a delegate was pushed off balance and he toppled over the rail into the chamber. He was fished out and his injuries were found to consist of a badly wounded dignity, some scratches and bruises, and an irreparably damaged wardrobe. He was taken to the locker room where he was given first aid by Dr. Jones, took a shower, and waited for clothing to be obtained from his home.

In the meantime, the remainder of the group moved on to the primary clarifiers, one of which Sam had had dewatered, the better to demonstrate its functions. Ascending the temporary wooden stairway that Sam had had constructed for their convenience, the delegates moved out onto the catwalk. There was no cause to be concerned here because Sam had issued emphatic instructions that the stairway be of rugged construction. It had shallow risers, wide treads and double, 2-by-4 railings. In fact, the carpenter had been so conscientious that he had provided a substantial slope on the treads to prevent the accumulation of water in the event of rain.

In any case, the group completed its inspection of this element of the plant and started elsewhere. Descending the stairway and for no obvious reason, one of the visitors pitched headlong to the ground. He was immediately examined by Dr. Jones who, by this time, had rejoined the delegation. Diagnosis—fractured clavicle. Being a hardy soul, the injured delegate insisted upon joining the visitor who had fallen into the grit chamber and, with him, waiting for the tour of the plant to be completed.

Undaunted, the remainder of the delegation continued their inspection. The next point of interest was the sludge pumping station. Mindful of the previously described unpleasantries, Sam had thoughtfully ordered all equipment in the station to be shut down temporarily. The group gathered around Sam while he explained the purposes and function of this element of the plant, that is, all the group but two who by this time had become fatigued.

The first tired visitor stayed in the background where he sat on his hands to rest. Unfortunately, he had selected as a prop for his hands a V-belt drive on a motor-compressor unit because of the resilient comfort it provided. The second weary visitor elected to lean against a column upon which the compressor switch was located. By sheer coincidence, his shoulder hit the "on" button of the switch. This set in motion a sequence of interesting events as you can well imagine. Suffice to say the first tired visitor got a manicure—which he needed anyway—but his nails were trimmed a bit short and the pattern of his fingerprints was altered considerably.

At this point, and by popular vote, it was decided to terminate the inspection. Accordingly, the delegation returned to the lunch room where Sam's three secretaries served a collation of cookies and tea.

The group then departed. One by one they filed past Sam, each expressing his profuse thanks for the edification and enjoyment that he had made possible. It occurred to Sam that three of his departing guests were not very enthusiastic and two of them did not offer to shake hands.

Last in line was Attorney Smith. He informed Sam that, during lulls in the tour, he had ascertained that his grit chamber railing was ten inches lower than prescribed by law; that the slope on the treads of the temporary stairway greatly exceeded the allowable limit; that, lacking a protective housing and a lock-out feature, his compressor switch was in violation of the law; and, finally, that his unguarded belt drive was clearly illegal. His parting comment was that it certainly had been a productive day for him. He had been retained to represent the injured guests, and it was his conservative estimate that the aggregate amount required to offset the mental anguish, indignities, damaged wardrobes, lost time, and medical expenses of his recently acquired clients would be in the magnitude of $100,000, exclusive, of course, of the special fees that would have to be paid to consulting engineers for their expert testimony.

As Sam reached into his desk drawer where he kept an emergency supply of ulcer medicine, the President of the Center County Wining and Dining Society returned to inform him that it was unlikely that any new members would be taken in that season.

The last we heard, Sam was residing in a sanitarium. He remains content and happy as long as he is kept supplied with sufficient counterfeit money to hand out to his fellow inmates whenever they suffer a real or imaginary injury from any cause.

DIFFUSER TUBE CLOGGING *

By W. N. Wells

Superintendent, Sewage Treatment Plant, San Antonio, Tex.

The air diffusion system is an important part of the activated sludge plant. Its function is to introduce air into the aeration tanks in a way which will maintain a certain level of dissolved oxygen in the mixed liquor to support the life processes of the necessary microorganisms. The clogging of the air diffusers is economically important to the sewage plant operator because the cost of compressing air and delivering it to the mixed liquor depends on the depth of the aeration tanks and the resistance to the passage of air offered by the diffuser. The static head is of course fixed by aeration tank design, but the resistance offered by diffusion media varies and becomes greater the longer diffusers remain in service.

The Water Pollution Control Federation's publication, "Air Diffusion in Sewage Works," discusses the various devices which have been proposed to introduce air into aeration tanks and lists a number of causes of clogging (1). The continuing appearance

* Presented at the Annual Meeting of the Texas Water and Sewage Works Assn.; College Station, Tex.; Mar. 1–6, 1959.

of new and different devices is an indication that a completely satisfactory solution to the clogging problem has not been found.

Observations of air diffusion equipment during normal operation of the San Antonio sewage treatment plant revealed considerable difference in the clogging characteristics of ceramic-type diffusers and plastic-wrapped stainless steel tubes.

The plastic-wrapped tubes require cleaning about once each year to maintain a satisfactory back pressure. The cause of clogging in this case seems to be carbonate formation, as acid cleaning brings the tubes back to a "like-new" condition. An alkaline detergent cleaner, as recommended by the manufacturer, was satisfactory for the first two times the tubes were cleaned, but it was not satisfactory on the third time.

The older aeration tanks at the San Antonio plant are equipped with square, porous, ceramic plates set in the bottom of the tanks. The only cleaning these plates have received in 29 years of operation is scrubbing with brushes when the tanks are dewatered for repairs at infrequent intervals. There has been some buildup of back pressure in these tanks as well as breaks in the plates which cause considerable loss of air and pressure. The breaks are periodically repaired with some difficulty, as the tanks must be dewatered. Except for the points where breaks occur, a satisfactory air pattern is maintained.

Test Installation and Procedure

For purposes of future plant design, it was decided to install several kinds of diffusers in a manner which would permit the determination of their clogging characteristics.

Experience indicates clogging is more rapid at the head end of aeration tanks, hence the diffusers to be tested were installed near the head of the tanks.

Tests were made on three kinds of diffusers, all of approximately 80 permeability *: ceramic tubes, plastic-wrapped stainless steel tubes, and a frame-mounted plastic fabric. Four diffusers of each type were installed on the end of a header at a submergence of 10.0 ft. The header was made of 1½-in. pipe and equipped with a ¾-in. brass orifice plate for measuring the volume of air flow. Petcocks were installed at suitable points for taking pressure readings and gate valves were used to control the air quantity.

The test procedure consisted of adjusting the valves to pass 24.5 cfm of air through each header and then observing the back pressure. Readings were continued even after a set of diffusers clogged to an extent that the air flow would fall below 24.5 cfm. Manufacturer's instructions for the fabric-covered frame called for "bumping" of the fabric by rapidly increasing and decreasing the pressure with a quick opening valve. Testing of this particular diffuser was discontinued after four months because of the rapid buildup of pressure. The plastic-wrapped tubes were acid cleaned in 50-per cent inhibited muriatic acid three times during the testing period which ran from Dec. 1956 to Feb. 1959. The ceramic tubes were not cleaned during this period.

Comparison of Results

To compare the clogging characteristics of the units after the set failed to pass the required 24.5 cfm of air, the volume divided by pressure was calculated and plotted against days of operation. The quantity v/p has the dimensions of cfm/psi and decreases as clogging increases.

The ceramic tubes were able to pass the required 24.5 cfm of air during

* Permeability is defined as the volume of air in cfm which is passed through 1 sq ft of diffuser, tested dry, at 2 in. water differential pressure, under standard conditions of temperature and humidity.

the entire test. There was an increase in back pressure of 0.98 psi during this period. Of this amount, the increase in back pressure during the last three months of the test was 0.68 psi.

The plastic-wrapped tubes were cleaned after 9 months, 14 months, and 19 months of operation. After the last cleaning, clogging occurred in four months. It was found that once the back pressure began to increase, clogging proceeded at a more rapid rate. After the last acid cleaning, very little clogging occurred for a period of about 60 days, but during the second 60-day period, clogging was rapid.

After acid cleaning, the plastic-wrapped tubes were restored to their original permeability. Several years of plant-scale experience with this type of unit have demonstrated that acid cleaning causes little weakening of the plastic.

Reference

1. "Air Diffusion in Sewage Works." Manual of Practice No. 5. Water Pollution Control Federation. Washington, D. C. (1952).

MEASURING THE ORP OF SEWAGE

By Clarence R. Henry

Research Chemist, Department of Water and Sewers, Miami, Fla.

Off hand, the measurement of the oxidation-reduction potential of sewage would seem simple and easy. Where the strengths of the oxidizing and reducing substances are known, the potential may be calculated. Where the potential is known, relative concentrations may be calculated. Sewage is quite like Pandora's box, however, and the strengths of oxidants and reductants are unknown. Moreover, simply measuring the ORP has its own share of difficulty.

A clean electrode is a prime requirement in measuring the ORP, and there exists a variety of recommended electrode-cleaning procedures. These include brisk rubbing with Bon-Ami, or rubbing with a dilute paste of hydrochloric acid and Alconox, or soaking in nitric acid, or electrolysis of the platinum electrode in dilute hydrochloric acid, all followed by thorough rinsing; or the electrode wire may be heated to redness.

One authority recommends that electrodes be discarded after "poisoning" or the production of erratic results, but does not describe the cause or nature of the poisoning. Nearly all reports on ORP measurement specify that three or more electrodes be used.

The diversity of opinion on techniques for measuring the ORP is emphasized further by the many notes about the time needed to get a stable reading. This runs from 3, to 10, to 30 min, with one writer specifying that each sewage demands its own special time.

This brings up another thought. Where time is needed to establish equilibrium, i.e., to get stable readings in an unstable sample, what is being measured? Are changes in the sample being followed or is it only electrode response?

The need for a careful procedure is emphasized by the nature of the sewage itself. The sample must be representative. No air may be added in the handling or during the measurement of the ORP. Settling must be prevented in most samples, but at the

same time stirring must not drape strands of anaerobic solids around a platinum wire electrode to give lower potentials. This is another way of saying that the measurements are best made in place, and not on dip samples.

This report is concerned with the difficulties in measuring potential. Included are discussions of:

1. Electrode behavior,
2. Calomel cell behavior,
3. Causes of error,
4. Design of an electrode carrier and field kit,
5. Useful features of the field kit and probe, and a
6. Procedure.

Electrode Behavior

Cleaning

A perfectly clean, bright, noble metal surface is necessary for potential measurement. The first work was done with two commercial "thimble-type" platinum electrodes. These gave variable results and the trouble was traced to the joint between the glass shank and the platinum tip. Unless the joint is perfectly tight, it can hold some of the materials used in cleaning, and readings even can be influenced by the character of the previous sample tested. Cleaning with Ajax household cleanser gave low potential readings because of its very high pH—about 11. Trace alkali effects were tested for by cleaning the electrodes, in series, with Ajax, caustic, soda ash, Bon-Ami (pH 9.6), and baking soda, and repeating in reverse order. Enough alkali was absorbed to interfere with measurements. Nitric acid not only removed the compound used in sealing the joint at the factory, but it was retained for a long time and caused high ORP values.

Cleaning by electrolysis in weak hydrochloric acid is recommended by the manufacturer. When the two thimble-type electrodes were electrolyzed against each other, they gave potentials as much as 400 mv apart when placed in the same sample, and they were 100 mv apart 10 min later. One of them was pre-reduced by the hydrogen made by the electric current, while the other was pre-oxidized by the chlorine. This persisted through repeated cleaning and rinsing of the electrodes and changing to samples of different potential.

Electrodes made by sealing 20-gage platinum wire in soft glass tubing were much better. They are easy to make, and cleaning is more positive; there is less joint between the platinum and glass to give trouble. The electrodes should be examined carefully with a magnifying glass from time to time because any crack which allows a connection between the sample and the mercury inside the glass tubing will produce high potential readings. Moisture within the glass tube and poor sealing of the platinum wire in the glass will do the same thing.

Electrodes should be cleaned by rubbing briskly with a mild neutral abrasive such as Bon-Ami or diatomaceous earth. Either may be used as a paste in water or isopropyl alcohol, or used dry occasionally to absorb oils and greases. All abrasive should be removed by thorough rinsing. Electrodes may be stored in distilled water for at least a day before use. Good response has been found after one hour's drying and after three hours of continued use. Occasional cleaning with very fine emery or carborundum is recommended for frosty gray areas which sometimes develop.

Response

The lead wire should be selected with care. Double-insulated (in plastic), shielded microphone cable (Belden 8401) is satisfactory. What is apparently "good" wire may be quite unsuitable. One wire tried had a hard waxy appearance, but became discolored and gave erratic results after a few minutes contact with water. Little

difference in response was found for lead lengths of 2 and 24 ft. The longer lengths of exposed platinum wire for the electrode seemed to shorten the response time somewhat.

Neither the exposed platinum wire nor the bare end of the electrode lead wire nor the setscrew with which it is connected to the pH meter may be handled after cleaning the platinum wire. The setscrew and lead wire should be handled with rubber gloves or with a dry cloth. Unless this is done, the grounding has a lasting effect. For example, an electrode grounded out gave a potential of − 1,040 mv at once, and recovered to only − 640 mv after the grounding connection was removed, and this was in a sample where three other electrodes measured − 450 mv.

When an electrode is disconnected from the pH meter, or lifted out of a sample, little effect may be found for a time. Readjusting the meter needle may be possible once, twice, or even three times, but the apparent potential changes and rapidly becomes uncertain. The meter needle becomes very erratic and then goes off scale entirely. Coating the electrode with asphalt has a similar, insulating effect. An acrylic spray coating also insulated the electrode, but had less effect; it is probably quite porous. Bacon grease, mineral oil, and oleomargarine seem to have little effect in samples near the zero level. On changing to a sample near − 400 mv potential, there was little response. Oils and greases reduce response and hold potential readings to a false high level.

Removing an electrode from the sample to the air, or even to the upper layer of a sample exposed to the air, will raise the potentials. No harm is done if the electrode is then put down with the other electrodes; its readings will simply be behind schedule.

Normal electrode response was found to take between two and five minutes. Readings are preferred from those electrodes which change the most during the first two minutes, and least after that. Continued recleaning of an electrode which gives high values lowers them to the level of other electrodes in the same sample. It does not raise them. The lower potential values of a group are to be favored. Where there is one variant electrode, the reading may be discarded, the electrode replaced, or all electrodes recleaned for comparison.

A long-time series of readings will trace the progress of staling of sewage—the values decrease and become more negative. A single test should not take more than 10 min. The practice at Miami is to take readings immediately and after 2, 5, and 10 min. The 5-min reading is usually reliable, and the downward drift in the second 5-min period is small.

Work here shows that instant response and exact agreement between two or more electrodes can not be expected. Generally, response was considered to be excellent if the over-all variation among four electrodes was less than 5 mv, very good at 10, and good at 20. When the variation is more than 40 mv, all electrodes should be recleaned and inspected.

In selecting potential values for record, the ones which are most quickly reached should be favored. High values may come from a coated or cracked electrode. Low values may come from poor electrical connections, grounding, or handling of the electrode lead. Where good agreement is not found among three electrodes, all should be cleaned. A stable value should be found in five minutes, with a minor drift to lower values in the following five-minute period. Drifting or erratic readings should be discarded.

Calomel Cell Behavior

The calomel cell should not be stored in distilled water nor placed directly in the sample. It is preferably kept in a reservoir of saturated potassium

chloride, with connection to the sample through a tube of saturated potassium chloride plugged with a glass rod.

Four commercial calomel cells have been tried, two of the asbestos-wick type and two of the palladium-wire liquid-junction type. All gave different values against the same platinum wire when placed directly in the sample; at times the difference was as much as 100 mv.

The cells were compared against each other by attaching one to the pH meter in place of the platinum electrode and balancing the meter. When the two cells were placed in saturated potassium chloride, no difference was found. Successive dilutions of the potassium chloride gave a 30-mv difference between the two. All cells were cleaned and wiped dry before use. Soaking the cells in distilled water before the trial increased this difference, while soaking in saturated potassium chloride decreased it.

When the calomel cell was connected to the sample through a tube of saturated potassium chloride, at lengths of up to 24 ft, all readings were the same. The standard cells were all in balance at zero potential, and all gave the same value against all four platinum wire electrodes in the same sample.

The tube connection to the sample is more than a convenience. It preserves the standard cell in a saturated potassium chloride solution and extends the allowable distance between the sample and the meter. This permits measurements to be made through the entire depth of a tank. The liquid junction is easily renewed by pinching the rubber to waste a few drops of KCl.

General Causes of Error

Some sources of error have been mentioned. Less obvious and harder to see are such things as moisture, handling and grounding of the electrode leads to the instrument, grounding of the pH meter case, faulty insulation of the leads, and loose connections.

Moisture within the pH meter case was the most important source of error and difficulty. Erratic readings caused by loose connections, cracks in the glass of the electrode, accidental or casual grounding of the meter, and faulty insulation were made worse by moisture.

The laboratory at Miami is in an air-conditioned building, but even this atmosphere failed to keep the meter dry. Indicating silica gel turned color in less than three days. Air-conditioning in this case meant only cooling to 80°F without drying.

The pH meter is now stored in a cabinet maintained at 95 to 100°F by a small light bulb and casual troubles have stopped. The case is opened once each week for inspection and replacement of the silica gel.

Design of Electrode Carrier and Field Kit

A field kit has been designed. It is essentially a carrying case for the pH meter and electrode carrier, or probe, which permits measurements to be made directly within the sample at distances up to 24 ft and more from the pH meter.

Electrode Carrier

The electrode carrier, or probe, is made from an 8-in. length of asbestos-cement pipe (Figure 1). One-half inch from the end of the pipe there are two ¼-in. holes and a loop of strong wire is run through them. To this wire, a supporting cord is attached. One inch from the end of the pipe there are four 9/16-in. holes 90 deg apart, and below these, are four more holes. These latter holes are 3 in. in from the other end of the pipe (see Figure 1). The 9/16-in. holes hold the electrode clips.

Clips to hold four electrodes inside the pipe are made from rubber stoppers. The narrow end of a No. 3 stopper is cemented to the wide end of a No. 2 stopper to form a smooth cone. Transverse holes are cut in the stoppers about ¼-in. from the widest end and

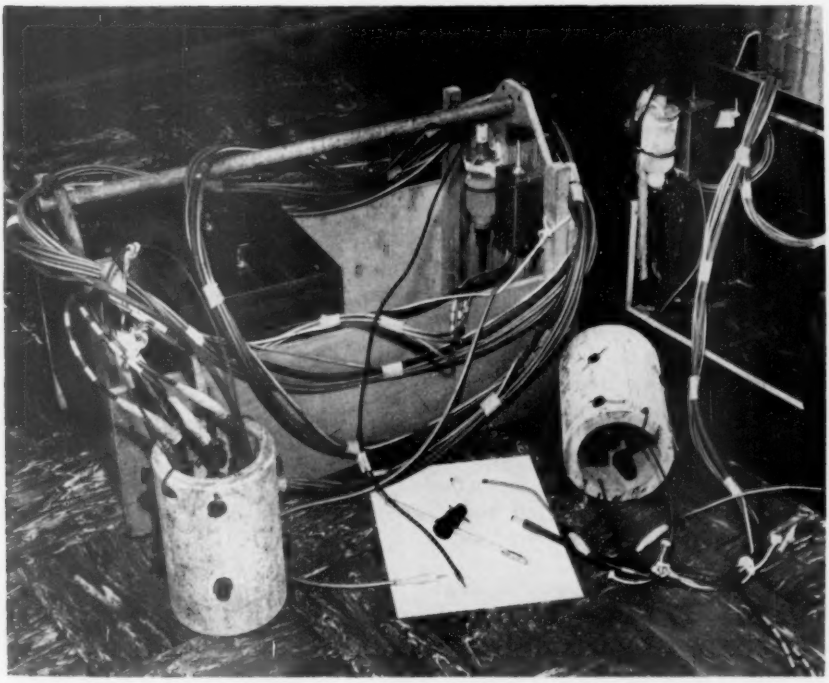

FIGURE 1.—Field kit for measuring ORP. The pH meter is on the left. The potassium chloride reservoir and multiple switch are attached to the end of the case. The single leads from the multiple switch and the standard cell are on the sheet of white paper. Also there are a single electrode in its rubber clip and the plugged end of the salt bridge. A stripped wire lead from the kit on the right is ready to be inserted into the homemade electrode.

then a wedge cut is made from the top of the stopper through to the hole. The narrow end of the stopper is pushed into the hole in the pipe and pegged outside with a thin nail. The glass tube electrodes then are slipped into position, with the end of the platinum wire ¼-in. from the end of the pipe.

Electrodes are made of 8-mm soft glass tubing. About 1¼-in. of 20-gage (0.032 in.) platinum wire is sealed into the end of an 8-in. length of tubing, with ¾ in. of platinum wire protruding. Contact is made to the lead wire by adding about ¾ in. of mercury to the inside of the tube.

The lead wire is a shielded microphone wire with plastic insulation. Connection to the electrode is made through a 2½-in. length of clear rubber tubing. The rubber tubing is tied into place after positioning it to allow a ½-in. slip-fit onto the end of the glass tubing. The tied end then is hot-dipped in asphalt and covered with tape.

The potassium chloride bridge is ¼-in. clear rubber tubing plugged with a 1-in. length of glass. This hangs loosely inside the carrier. Beginning about 3 ft from the bottom of the carrier with about 6 in. of slack in the electrode leads, the salt bridge, leads, and ¼-in. nylon cord are taped together. The 5- and 10-ft marks are double-taped for ease in estimating depths. The end of the 24-ft support cable is tied to the carrying case, with 6 in. of slack in the leads and KCl tube.

Carrying Case

The carrying case (Figure 1) holds the pH meter, the coiled cable, electrode carrier, cleaning materials, extra electrodes, etc. It looks like a carpenter's tool box. The 1-in. corner posts protrude 2 in. above the sides to hold the coiled cable in transit and storage. The handle is removable. The second model is 22 in. long and the handle is fixed. Part of one side is cut out to allow removal of the pH meter.

A multiple switch and a KCl reservoir are mounted on the inside end of the case. Four electrode leads are attached to the switch and a single lead goes to the meter. The reservoir is made from a plastic bottle with the bottom cut off. A two-hole rubber stopper holds the calomel cell and allows for expansion and protection of the KCl.

In use, the calomel cell and the single lead from the switch are connected to the meter. The electrodes are cleaned, and a few drops of KCl are bled from the end of the rubber tube before it is placed inside the carrier. After rinsing the electrodes, the carrier is lowered into the sewage to the desired depth. Raising and lowering the carrier in the sewage gives further rinsing, and, in effect, resampling. The dial knob of the meter is then pushed down and locked, and the instrument needle is balanced for reading the potential in the usual way. Different electrodes are then connected by operating the multiple switch, which should not be wired with an "off" position.

The carrying case, with 24-ft cable and electrode carrier, weighs 23 pounds. Materials for the carrier, case, and platinum wire cost about $30.

Useful Features of the Field Kit

This kit provides for storage and transport of all items needed to measure electrode potentials. Measurements are made directly in the flow of sewage and at any depth within a tank. The standard cell is kept soaking in a saturated KCl reservoir which is extended some considerable distance by a rubber tube. Connection to the sample is made through a seal made by a plug in the tube. This involves at most a 5-ft head of water pressure on the KCl tube extension (the height of the meter above the sewage flow). The plug may be taped in place to allow for additional head and in this way measurements can be made at lower elevations to avoid poisonous gases or travel on a narrow ladder.

The electrode carrier is almost nonfouling, and the electrodes may be rinsed with fresh sample without removing them from the sewage flow. The multiple switch in addition to being convenient makes the handling of electrode leads unnecessary.

Procedure for Use of Field Kit

1. Open pH meter, turn on to warm up. Attach plugs from standard cell and multiple switch. Turn "pH" switch to "millivolts."

2. Clean all electrodes by rubbing briskly with Bon-Ami or diatomaceous earth on a clean cloth. This may be moistened with water or isopropyl alcohol. Use very fine emery or carborundum powder at the beginning of each week of use.

3. Rinse electrodes thoroughly, preferably by whipping the platinum wire end in a small bucketful of liquid. Place electrode in rubber clip inside carrier. Leave ¼ in. space to end of carrier. Place electrode carrier in sample.

4. Push down and lock the button on the pH meter dial knob.

5. Read potentials in the usual way. Change from one electrode to another by using the multiple switch.

Notes

(*a*) Neither the bare electrode lead nor the setscrew attaching it to the pH meter may be handled after cleaning the electrode.

(*b*) Normally, readings should be taken immediately and at 2, 5, and 10 min. In profile work, after the first 10 min, the electrodes may be raised or lowered to a new position and readings taken in 2 to 5 min.

(*c*) Readings should be favored which change (decrease) the most in the first 2 min, and the least after that. Lower potentials and those from the most recently cleaned electrodes tend to be the more accurate.

(*d*) Results are excellent when the over-all potential spread from the four electrodes is less than 10 mv, good if less than 20. If there is more than 40 mv spread among three, clean all of them.

BOD SHOCK LOAD

By Galen Gault

Superintendent, Delta Water and Sewage Department, Delta, Ohio

Delta, Ohio, has a population of approximately 2,400 and the major industrial waste contributor is a milk company. The sewage treatment plant is a compact activated sludge facility.

The major treatment problem is the waste milk from condensing operations. This problem was anticipated by the designers and the milk company. Although the company has developed a program to keep waste at a minimum, an unusual waste is discharged occasionally. When this happens they alert the treatment plant.

The milk tends to produce a lightweight sludge. To offset this effect, a high rate of return is used. This runs as high as 43 per cent in normal operation.

On Sept. 3, 1958, the company called saying a considerable amount of condensed milk had entered the sewer accidentally. Immediately, the return sludge was increased to 63 per cent and the air supply was increased to 2 cu ft/gal of sewage.

The milk entered the plant, and a catch sample taken from the raw inlet channel showed a 5-day BOD in excess of 37,000 mg/l and a total solids of 39,930 mg/l. The composite samples were taken from 8 AM to 4 PM of that day: the raw sewage BOD was 1,472 mg/l; the primary effluent, 486 mg/l; and final effluent, 2.9 mg/l. Since the flow took about 12 hr to go through the plant, the effect of the excess milk did not show in the final settling tank until the next day.

After the milk had entered the plant, raw sewage was directed periodically into the aeration chamber without primary treatment. At the same time, return sludge was wasted at a rate of approximately 30 per cent. The purpose was to remove the light sludge produced by the milk and replace it as fast as possible with a more dense sludge built around the solids in the raw sewage.

Although the dissolved oxygen in the final dropped from 2.6 to 0.3 mg/l the next day, the technique proved to be effective. At the end of the second day only 0.2 ml/l of settleable solids was present in the final effluent. After five days, the BOD of the final effluent was 2.0 mg/l and it had a dissolved oxygen concentration of 2.2 mg/l.

Had the plant not been alerted about the condensed-milk spill, the treatment process would have been completely destroyed. This cooperation between industry and the municipality makes for better pollution control as well as a better respect and understanding of each other's problems.

TIPS AND QUIPS

Lucky Lookers

Those people out in St. Louis are always finding things. First it was a flooded wine cellar and now it is a "threshing machine" wheel that was filled with concrete to make a homemade manhole cover (see below). What they never tell, though, is what happened to the wine, or where is all the money we're sure they're always finding, or where is the Jaguar that was connected to that darn wire wheel.

"Threshing machine" manhole cover.

Regional Planning

Coordination of sewerage and water supply problems in the Washington, D. C., area is expected to be brought about by the newly formed Washington Metropolitan Regional Sanitary Board. The Board will act as an adviser to the National Capital Regional Planning Council.

Twenty-two agencies will be represented on the Board. The first project will be a preliminary study and report on a regional master plan for sewers and wastewater disposal. Financial support for this important work already is assured.

Motors

"The ABC of Motor Mechanics" is the title of a 34-page booklet published by the Electric Machinery Mfg. Company, Minneapolis 13, Minn. This extremely useful issue "brings together . . . many of the mechanical items that come up for consideration before, during and after the installation of large a-c motors." Nearly two-thirds of the contents are devoted to installation and maintenance procedures.

The pressure of public opinion is like the pressure of the atmosphere; you can't see it—but all the same, it is sixteen pounds to the square inch.

JAMES RUSSELL LOWELL

Safety

Two recent publications of the National Safety Council, 425 North Michigan Ave., Chicago 11, Ill., will be of interest to many readers.

The first is Data Sheet 239, "Barricades and Warning Devices for Highway Construction Work"; the second, Safe Practices Pamphlet No. 1, "Ladders." Both are filled with much useful information.

Landscaping

Russell Grinnell, superintendent of the Birmingham, Mich., sewage treatment plant at 151 Martin St., has started a comprehensive collection of pictures of the results of plant beautification. He is interested in both color slides and black-and-white prints. Any help you can give him will be appreciated.

We live under a government of men —and morning newspapers.

WENDELL PHILLIPS

Editorial

THE TURNING POINT

The Federation meeting in Philadelphia is particularly significant in this election year which could be the turning point in the water pollution problem. As all who have followed the recent political conventions are aware, there is greatly intensified emphasis on water pollution control. In other years at other conventions we do not recall this awareness of pollution control needs by principal political speakers. This can be viewed only one way—regardless of who is living at 1600 Pennsylvania Avenue, a strong part of his program will be aimed at this growing problem. It has been repeated that only expanded attention at the national level can stop the rising backlog of treatment needs and provide the impetus for beginning to "catch up." This attention now appears imminent.

With these developments in mind, the Philadelphia meeting of the Federation (its 33rd annual gathering), October 2–6, sets the stage for the "Soaring 60's" in water pollution control.

You are a part of the group speaking for the water pollution control interests and making the important decisions toward the solution to these problems. So, come and add your voice and thoughts.

The meeting is to be favored by speakers who are in the best possible situation to provide timely words. The Honorable Arthur S. Flemming, Secretary of the Department of Health, Education, and Welfare, will address the annual Federation luncheon. Robert G. Dunlop, President of the Sun Oil Co., will talk at the INDUSTRY DAY luncheon.

This year, industrial problems will command increased attention. For example, Wednesday has been designated INDUSTRY DAY and features special papers by and for industry, as well as the Industry Luncheon. A record turnout of industrial representatives, many for the first time, is expected to swell the attendance.

No meeting in the past has had the quantity and variety of the exhibits to be shown in Philadelphia. The Convention Hall offers unlimited space for exhibitors to put on their best show. You cannot spend a better hour, or half day for that matter, than giving the exhibits a close look. You will come away with many questions answered and many new ideas.

The credit for the multitude of preparatory details necessary for the meeting goes to the Local Arrangements Committee of the Pennsylvania Sewage and Industrial Wastes Association, under the Chairmanship of Samuel S. Baxter, Commissioner of Water for the city of Philadelphia. The Chairman is ably assisted by Vice-Chairmen A. A. Estrada and S. I. Zack, and the following Subcommittee Chairmen: B. B. Palmer, Registration; J. J. Gilbert, Hotel Arrangements; S. E. Kappe, Host; G. A. Howell, Publicity; R. Hoot, Inspection Trips; M. L. Hicks, General Entertainment; G. A. Elias, Finance; J. T. Cappio, Transportation; and Mrs. S. S. Baxter, Ladies Entertainment.

If you have not already done so, you are urged to review the details of the Convention Flyer mailing for your preregistration and hotel reservation forms, as well as other details of the meeting.

R. E. F.

News and Notes

Of Persons and Activities in the Wastewater Field

R. S. (Steve) Rankin died recently in Stamford, Conn. He had retired from **Dorr-Oliver** in 1956 as Director of Sanitary Technical Engineering, after 30 years of active service, and was until his death a consultant to the company. Steve had been active in Federation affairs for many years.

Leo Weaver is the new Chief of the Water Quality Section at the Public Health Service's Robert A. Taft Sanitary Engineering Center in Cincinnati. For the past two years he has been with the American Public Works Association as Assistant Director and Director of Research.

Eugene H. Trubnick, long-time associate of **Komline-Sanderson Engineering Corporation,** died recently.

Fisher Scientific Company, Pittsburgh, has acquired Industrial Scientific, Inc., as a wholly-owned subsidiary.

Ernest R. Roth, formerly in charge of Atlantic Refining Company's Industrial Wastes Engineering Section, has been placed in charge of the air pollution activities of the Research, Development and Consulting Division of **Roy F. Weston, Inc.,** Newtown Square, Pa.

Harry E. Schlenz, President of the **Pacific Flush Tank Co.,** Chicago, has been appointed to the Steering Committee of President Eisenhower's National Conference on Water Pollution. He is a member of the Federation Board of Control.

William Q. Kehr recently resigned as Executive Director of the Metropolitan St. Louis Sewer District in St. Louis, Mo. He has accepted a position with the Public Health Service in Washington.

Daniel A. Okun, Professor of Sanitary Engineering and Head of the Department of Sanitary Engineering of the School of Public Health at the University of North Carolina, will be in the Netherlands for the 1960–61 academic year at the Technological University in Delft under a National Science Foundation Senior Postdoctoral Fellowship. He will conduct investigations at the Research Institute of Public Health Engineering in the Hague.

John C. Loos, Jr. has been made Assistant to the President, and **John E. Pearah** has been appointed Chief Engineer of The American Well Works, Aurora and Chicago, Ill.

D. A. Dahlstrom, Director of Research and Development at **The Eimco Corporation's** Palatine, Illinois location, has been elected a Vice-President.

E. C. Aldersey, Town Engineer at Trenton, Ontario, has resigned to become City Engineer at Barrie, Ontario.

Douglas C. Reybold is now in charge of the research, development, legal, and patent functions for **Dorr-Oliver Inc.** in Stamford, Conn.

Robert T. Bailey, City Engineer of St. Catherines, has been appointed City Engineer of Windsor, Ontario.

K. E. Carrington has been named Acting Superintendent to succeed **Howard Holcomb** at the Cortland, N. Y., sewage treatment plant.

Robert K. Barefoot of Chagrin Falls, Ohio, and **Finley G. Van Brocklin** of Memphis, Tenn., have become manufacturer's representatives for **Smith & Loveless,** Lenexa, Kans.

Frederick W. Crane, General Manager of the Buffalo, N. Y., Sewer Authority, has been nominated for President of the American Public Works Association.

F. S. Weir has been elected to the position of Vice-President of the Export Division and the Equipment Application Department; and **D. E. Dreier** has assumed the post of Vice-President and Chief of Engineering and Research of **Walker Process Equipment Inc.,** Aurora, Ill.

Ray J. Desmarais, former City Engineer-Manager of Windsor, Ontario, has taken over the new Windsor office of M. M. Dillon and Co.

Adolph Koebig, Jr., President and Chairman of the Board of **Koebig and Koebig,** Los Angeles, died while attending the recent meeting of the California Sewage and Industrial Wastes Association.

Edward R. Lassone, of Schwenksville, Pa., is now a Service Engineer for Keasbey and Mattison.

John G. Hoyt, Jr. has been appointed product sales manager of **Rockwell Manufacturing Company's** Municipal and Utility Division.

Book Reviews

The Biology of Polluted Waters. By H. B. N. Hynes. Liverpool University Press, 123 Grove Street, Liverpool 7, England. 216 pp. Price $4.00 postpaid (1960).

This book presents biological aspects of polluted waters comprehensively but in simple terms. A general outline of the biology of unpolluted inland waters is included to guide the reader unfamiliar with the science of fresh water biology.

A general account of the various types of effluents along with their chemical and physical effects upon rivers and streams is given. The biological consequences of each type of pollution are considered with the special case of lake pollution and its relation to water quality.

Photographs, illustrations, and an extensive bibliography make this a valuable reference to those concerned professionally with this problem.

R. E. F.

Chemistry for Sanitary Engineers. By Clair N. Sawyer. McGraw-Hill Book Co., New York. 367 pp. Price $9.50 (1960).

Sanitary engineers everywhere should be thankful that Dr. Sawyer has the courage of his convictions. Without it, we should have no book. For as the author points out, it took some courage to reduce the basic concepts of sanitary chemistry to eight chapters. It is precisely in the chapter for which he expresses misgiving—the chapter on organic chemistry—that he scores his finest triumph.

What Dr. Sawyer has written is an introduction to sanitary chemistry based on fundamental principles. At times, the temptation to expand must have been unbearable, but fortunately there was no yielding.

Approximately half of the book is given over to fundamentals; the other half is devoted to water and wastewater analysis. In the eight basic chapters, general, qualitative, quantitative, organic, physical, colloid, bio-, and radio-chemistry are discussed. In the 24 chapters on water and wastewater analysis, the chemistry and significance of all common tests are rather closely examined.

Working on the premise that an introductory textbook should "stimulate the student's desire to learn more chemistry," Dr. Sawyer, in example after example, demonstrates the practical side of the principles of sanitary chemistry.

R. A. G.

The Treatment of Trade-Waste Waters and the Prevention of River Pollution. Edited by Peter C. G. Isaac. Public Health Engineering Section, Department of Civil Engineering, University of Durham, King's College, Newcastle upon Tyne, 1, England. 311 pp. Price, 45 shillings (1957).

The book is a collection of the lectures given at a course held in the Department of Civil Engineering, King's College, Newcastle upon Tyne, April 1 to 12, 1957. The lecturers included many notable figures in river pollution and waste-water treatment in Great Britain.

Lectures are presented as chapters with all authors indicated. The chapters are:

A Survey of the Problem of Trade-Waste Waters.
River Pollution—General and Chemical Effects.
River Pollution—Biological Effects.
Discharge of Trade Wastes—The Legal Position.
The Impact of Trade Wastes on Sewage-Treatment Practice.
A Survey of Trade-Waste Treatment.
The Analysis of Trade-Waste Waters.
Simplified Statistics for Analytical Chemists.
Photoelectric Instruments in the Measurement of Trade Wastes.
pH Instrumentation in Industry.
Instrumentation and Automatic Control in the Treatment of Trade Wastes.
The Biological Oxidation of Trade Wastes.

Activated Sludge for the Treatment of Trade Wastes.
Physical Methods for the Treatment of Trade Wastes.
Treatment-Plant Engineering.
Chlorination in the Treatment of Trade Wastes with Special Reference to Cyanide Effluents.
Treatment of Wastes from the Refining and Processing of Metals.
The Treatment of Waste Liquors from the Manufacture and Processing of Rayon.
The Treatment of Papermill Wastes.
The Purification of Coke-Oven Liquors by Ion Exchange and Activated Carbon.
The Use of Activated Charcoal in the Treatment of Trade Wastes.
The Treatment, Conveyance and Disposal of Radioactive Wastes.

R. E. F.

Environmental Sanitation. By Joseph A. Salvato, Jr. John Wiley & Sons, Inc., New York. 660 pp. Price $12.00 (1958).

Mr. Salvato has drawn on his valuable experience as a practitioner of public health engineering to write a thorough and practical treatise on environmental sanitation. The author continually demonstrates how engineering principles may be applied to many of the every-day problems which face the local health authority.

In eight chapters, he covers: communicable disease control, location and planning, water supply, sewage and industrial wastes, swimming pools and beaches, food, insects and rodent control, housing, and administration.

More than 100 pages are devoted to sewage and industrial waste treatment and disposal. Discussions are replete with diagrams and design data, especially for the small system; and much of the information is based on proved methods.

The author hopes that as a side effect the book will stimulate a search for better methods of making the environment safe and salutary. The recent questioning of the value of distribution boxes in tile fields as well as enlarged concepts on what kind of individual household system is justified economically are two examples of the value of a fresh look at old problems.

This book will be welcomed by sanitary engineers and sanitarians as a first-rate addition to the meager supply of reference volumes dealing with this topic.

R. A. G.

Manual on Industrial Water and Industrial Waste Water. Second Edition, ASTM Special Technical Publication No. 148-D. American Society for Testing Materials, Philadelphia, Pa. 624 pp. Price $11.00; to Members, $8.80 (1959).

For executives, plant managers, and designers, this manual offers information on the influence of water on industries. To operating personnel, it provides a guide to the significance of treatment and gives general discussions of industrial water use, conservation, and treatment. Chemists and other technologists will find in the volume the ASTM standard methods for sampling, analyzing, testing, and reporting results.

This second edition offers a substantial expansion of the first. About one third of the book is devoted to the general uses and problems of sampling and analysis. The remainder of the volume is comprised of ASTM standards on industrial water including sampling, methods of testing, and analytical results.

R. E. F.

Data Book for Civil Engineers—Design. By Elwyn E. Seelye. Volume 1, Third Edition. John Wiley & Sons, Inc., New York, N. Y. 683 pp. Price $24 (1960).

Like the preceding editions, this volume gives, in the form of tabulations and figures, much basic data of the civil engineering field. A detailed index makes it easy to find specific information.

Chapter headings of particular value to those engaged in wastewater technology include Waterfront Structures, Drainage and Sewerage, and Sewage Treatment. In addition, chapters on Water Supply, Water Purification, and Water Distribution contain much information on hydraulics and many other applicable subjects.

New material of special interest has been added to the following subjects: pipe bearing strengths related to bedding conditions and height of fill, manhole covers, sewage screening, sludge digestion and heating by external heaters, sludge thickening and elutriation, pumping station electrical installation, chlorination, and small treatment plants.

R. E. F.

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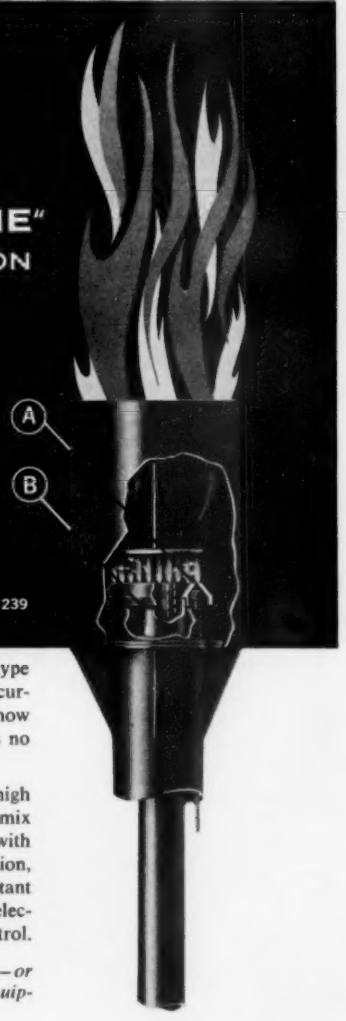

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WATER POLLUTION CONTROL PRODUCT GUIDE

This list of products and services is offered as an information aid. The list was derived by solicitation from those firms listed. The JOURNAL will make every effort to keep this list current with the help of members and advertisers. All Associate Members and all advertisers for the past year are included. Many of the services and products are advertised in this issue. For an alphabetical listing see Index to Advertisers in back of JOURNAL.

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Proceedings of Member Associations

NEW JERSEY SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 45th Annual Meeting of the New Jersey Sewage and Industrial Wastes Association was held at the Hotel Traymore, Atlantic City, N. J., on Mar. 30–Apr. 1, 1960. Attendance totaled 490, including 50 ladies.

The papers touched on nearly every phase of wastewater handling and included:

"Recognition and Solution of an Industrial Waste Problem," by Morris B. Smith, Moderator, Superintendent, Waste Treatment, Toms River—Cincinnati Chemical Co., Toms River, N. J.

"Recognition and Definition of an Industrial Wastes Problem," by L. W. Roznoy, Director of Air and Water Pollution Control, Olin Mathieson Chemical Co., New York, N. Y.

"Methods of Solution," by C. Fred Gurnham, Head, Department of Chemical Engineering, Michigan State University, East Lansing, Mich., and Roy F. Weston, Consulting Engineer, Newtown Square, Pa.

"Implementation of Solution," by John Baffa, Consulting Engineer, New York, N. Y.

"Proving Solution," by A. B. Cherry, Jr., Sanitary Engineer, American Cyanamid Co., Bound Brook, N. J.

"Proving and Compliance," by J. C. Lamb III, Associate Professor of Sanitary Engineering, University of North Carolina, Chapel Hill, N. C.

(*Continued on page 411a*)

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"Safety in Sewerage," by Charles Hammann and C. Y. Hitchcock, Metcalf and Eddy, Boston, Mass.

"Automation through Comminution," by W. W. Wilmarth, Worthington Corp., Harrison, N. J.

"The Delaware River Basin Program," by James Allen, Executive Secretary, Interstate Commission on the Delaware River Basin, Philadelphia, Pa.

"The Walker Process Gaslifter," by Charles Perron, Dravo Corp., New York, N. Y.

"The End Result," by George Shay, Somerville, N. J.

"Non-Lubricated Plug Valves," by David DeZurik, Sr., President, DeZurik Corp., Sartell, Minn.

"The Raritan Valley Project," panel discussion.

"Training Programs and Licensing Examination for Operators," panel discussion.

Greetings from the Federation were brought by Past-President W. D. Hatfield who also addressed the Operators' Breakfast. At the business session, action was taken to change the Association's name to the New Jersey Water Pollution Control Association.

The following officers were elected:

President: Michael Kachorsky, Manville.

1st Vice-President: John Frazee, Camden.

Secretary: Anthony T. Leahey, Trenton.

Treasurer: Henry Van Der Vliet, Rutherford.

Director: John J. Horgan, Hackensack.

ANTHONY T. LEAHEY
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(*Continued on page 413a*)

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Sewerage was held at the Louisiana State University, Baton Rouge, La., Mar. 16–18, 1960. Total registration was approximately 200.

Concurrent sessions were held on water supply, sewerage, and industrial wastes. Action was taken to change the name of the Waste Section to the Water Pollution Control Association.

The officers elected for 1960–61 are:

Chairman: A. J. Szabo, Lafayette.
Director: Edmond E. Dupre, Lafayette.
Secretary-Treasurer: George H. West, Lake Charles.

GEORGE H. WEST
Secretary-Treasurer

ARKANSAS WATER AND SEWAGE CONFERENCE

The Arkansas Water and Sewage Conference and Short School were held at the Hotel Marion, Little Rock, Ark., on Mar. 14–16, 1960. Total registration was 298.

Presentations concerned with wastewater collection and treatment were:

"Free Money and How to Get It," by M. L. Wood, Director, Arkansas Water Pollution Control Commission, Little Rock, Ark.

"Package Sewage Treatment Units for Isolated Subdivisions," by F. E. Wingfield, Sales Representative, Infilco, Inc., Tulsa, Okla.

"Sewer Ordinances," by T. W. Clapham, Manager, Sanitary Sewer System, Little Rock, Ark.

"Oxidation Ponds," panel discussion.

At the business meeting, the following officers were elected for the year 1960–61:

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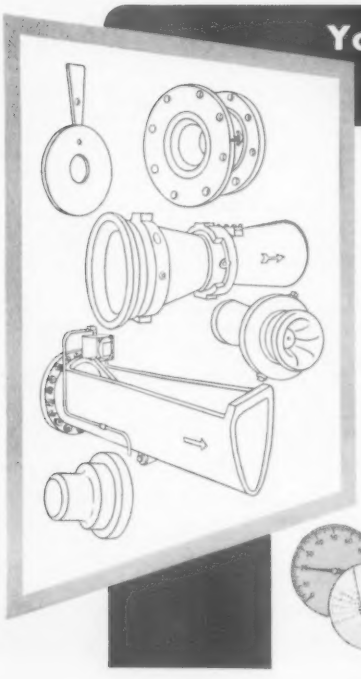

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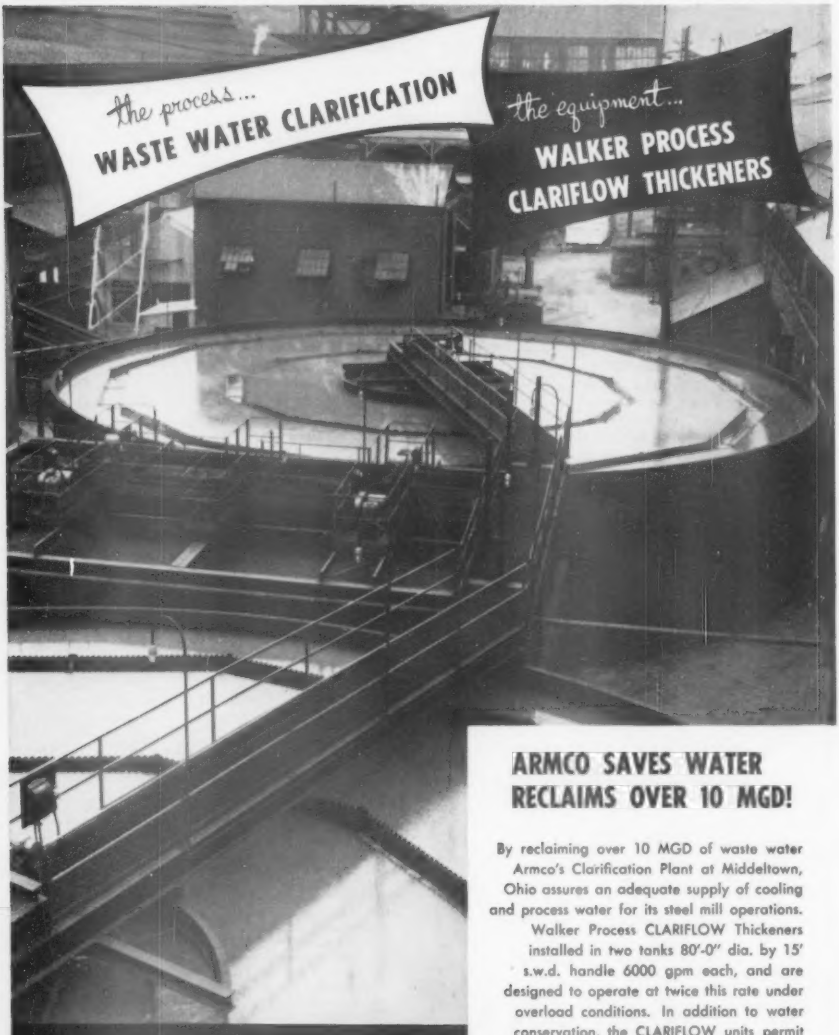

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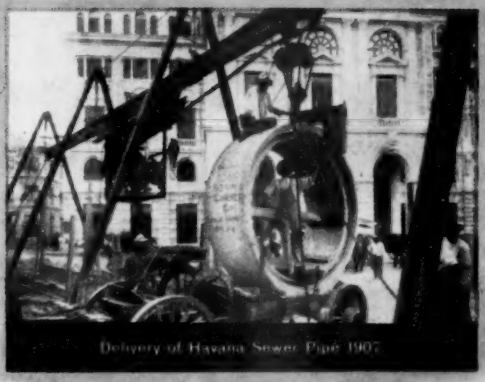

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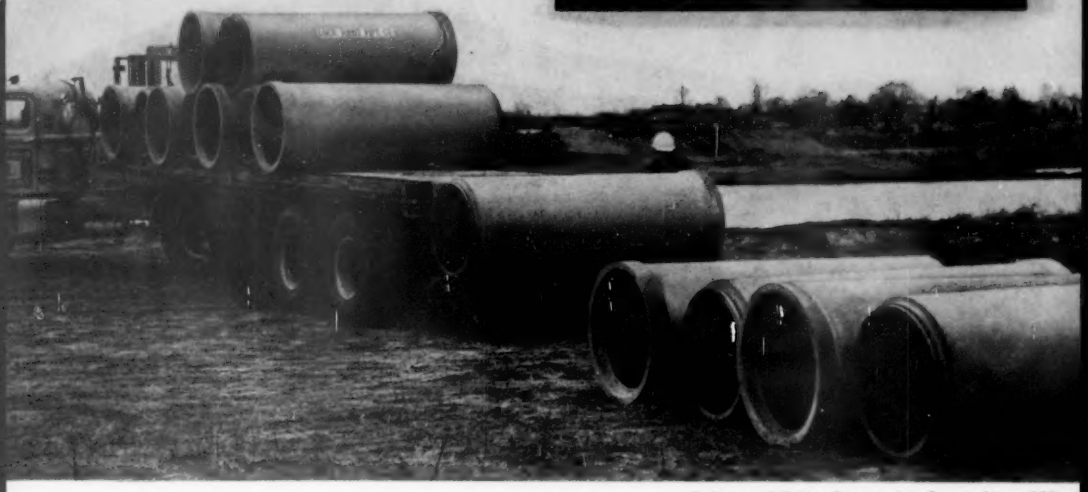

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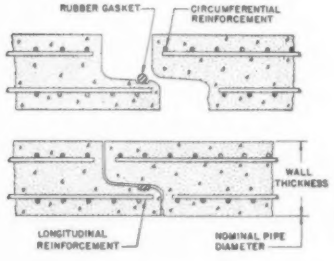

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